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Water uptake depth does not explain drought exposure or response in rainfed Mediterranean grapevines: An isotope-based study

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ABSTRACT

The ample diversity in grapevine genotypes and their contrasting physiological responses to drought can be used by winegrowers to adapt to the increasingly drier conditions imposed by climate change. Still, the exposure to drought is more strongly associated with the rootstock genotype onto which grape scions are grafted. Indeed, certain rootstocks help maintain higher yields in drought conditions. Although some morphological, developmental, and physiological rootstock traits have been associated with greater drought resistance, information on how grapevine rootstocks access and use belowground water sources in field conditions is scarce. Besides, the rootstock–scion interaction could modulate root growth, which may dictate root depth and root water uptake. Deciphering the grapevine belowground activity is critical to decide which rootstock is more suitable for each agronomic situation. Isotopic tracers ($\delta^{18}O$ and $\delta^{2}H$) are a promising tool to study grapevine water sources, but they have been seldom used for phenotyping. Here we aimed to test whether different rootstocks influence the grapevine's access to water, impacting whole-plant water status, plant growth, and yield, and whether the rootstock–scion interaction plays a role in the magnitude of this impact. To do so, we combined isotopic-based determination of grapevine water sources with monitoring of physiological and agronomic performance in an experimental vineyard with 9 rootstock–scion combinations (3 rootstocks × 3 scions). We found significant effects of the scion on the above-ground plant water use (*e.g.*, midday water potential), whereas the rootstock had significant effects on the predawn water potential. Surprisingly, isotopic tracers revealed that all rootstocks were accessing a similar belowground water pool, despite different predawn water potentials. This suggests that the lower exposure to drought offered by one of the studied rootstocks (110-R) is not caused by a deeper root system, but likely by other morphological, anatomical, or physiological traits that remain to be explored. In addition, we observed that plants rapidly took up water after the first substantial rain events following the summer drought, around harvest. Overall, we show that isotopic techniques can provide information on grapevines' access to water that can guide vineyard management and rootstock phenotyping.

KEYWORDS: $\delta^{18}O$ and $\delta^{2}H$, viticulture, plant water use, rooting depth, rootstock phenotyping, water tracers

INTRODUCTION

Wine-growing regions located along the Mediterranean basin are expected to suffer from moderate to high increases in drought levels even under the most optimistic climate scenarios (van Leeuwen *et al*., 2024). Increases in drought will be caused both by rising temperatures and more irregular precipitation, but at the plant level, they can also be amplified by climate-induced phenological changes (Sgubin *et al*., 2023). Altogether, the decrease in water availability is predicted to result in yield and quality penalties (Romero *et al*., 2016). In this context, a number of mitigation strategies have been proposed, including canopy management to reduce water demand (Poni *et al*., 2023), irrigation (Savi *et al*., 2018; Zarrouk *et al*., 2015), and varietal shift (Wolkovich *et al*., 2018). The suitability of different strategies in each agronomic situation is a function of many factors that are not always under the control of winegrowers, *e.g.*, the water supply for irrigation is not always accessible. Nonetheless, the factors associated with drought stress are far clearer from the physiological point of view. Access to water is determined by the volume explored by the root system and the soil properties, whereas how the water is accessed and spent depends on the above-ground part of the plant (Gambetta *et al*., 2020). The subject is far from simple, largely due to the intricate interdependence between these two components. Rootstock–scion interaction could modulate root growth through source-sink relationships driven by scion-specific ecophysiological behaviour (Damásio *et al*., 2025; Dayer *et al*., 2022), which in turn govern root growth, depth, and root water uptake (Ollat *et al*., 2025). Therefore, the evaluation of drought-adaptation strategies in Mediterranean viticulture should adopt integrative approaches that consider both the root access to water and scion (*i.e*., cultivar) water use.

In contrast to the extensive knowledge on scion-specific above-ground responses to drought (Dayer *et al*., 2022; Lamarque *et al*., 2023), our knowledge of the structure and function of grapevine root systems in field conditions is more limited, mainly because observing below-ground processes is technically challenging. However, studies using root observation tubes (minirhizotrons) (Alsina *et al*., 2011) and analyses of the whole-plant 3-D architecture through excavations (Fichtl *et al*., 2025) have shown the important impact that different rootstock genotypes have on the morphology of grapevine root systems and, consequently, on water uptake. However, because such destructive and/or time-consuming methodologies cannot always be used for rapid phenotyping, we need indirect methods with higher throughput. In this context, the use of isotopic tracers (δ^2H and $\delta^{18}O$ in water) is a useful technique to study plant water source and make inferences about the extent of the root system. This technique has been introduced to agronomical science from the hydrological and ecological sciences, providing valuable insights about management practices in woody crops (Penna *et al*., 2020). Early isotopic applications in vineyards suggested that measuring δ^2H and $\delta^{18}O$ in xylem water and potential water sources can be used to trace the main water source used by grapevines (Savi *et al*., 2018). Similarly, isotopic-based approaches can be used to decipher the timing and origin of water taken up by grapevines by observing the temporal changes of the water isotopic signature along the season (Benettin *et al*., 2025). Isotopic tracers should thus be explored for phenotyping rootstocks in the quest for drought-resistant root ideotypes (Bernardo *et al*., 2025).

In this study, we combined physiological and agronomical measurements with isotopic-based determination of grapevine water sources in an experimental vineyard with 9 different combinations of *Vitis* rootstocks and scions. Our aim was (i) to test whether the rootstock determines the depth of root water uptake, and thus the plant access to water, (ii) to determine the effect of the rootstock-mediated access to water on the physiological status and the agronomical performance of the grafted scions, and (iii) to evaluate the role of the rootstock-scion interaction on both the grapevine's physiology and the agronomical parameters.

MATERIALS AND METHODS

1. Experimental vineyard and environmental monitoring

The study was conducted at the experimental vineyard of IRTA (41.613230, 2.166611) in Caldes de Montbui (Catalonia, Spain, Figure S1), under a Mediterranean climate (*Cfa* in the Köppen-Geiger classification for the period 1991–2020, Beck *et al*., 2023). A weather station belonging to the Network of Automatic Weather Stations (AWS) managed by the SMC (Catalan Meteorological Service) located 100 m from the vineyard reports a mean annual temperature (MAT) of 14.6 °C and a mean annual precipitation (MAP) of 615 mm for the period 1950–2024. Warmer but slightly wetter-than-average conditions occurred during the study year (2024): a MAT of 15.9 °C, a MAP of 670 mm, with relatively wet spring and autumn but a dry summer (Figure 1). Soil volumetric water content (VWC, %) in the vineyard was monitored at 30 cm depth with TEROS 10 sensors (METER, Pullman, WA, USA). The experimental plot has a total of 0.6 ha and was planted in 2009 with a planting spacing of 1.2 × 3 m and NNW–SSE oriented. Vines are trained with a single Cordon de Royat and are spur pruned in winter. We used a subplot inside the vineyard with a fully randomised design (Figure S2), with 9 combinations of rootstock (Richter 110 (110R), 140 Ruggieri (140Ru), and 41B Millardet et de Grasset (41B)), and scion (Cabernet-Sauvignon (Cabernet S), Grenache, and Marselan), with 3 blocks for each combination. A green spontaneous cover has existed on the plot's soil since 2020. This cover is mowed at the end of the spring season to avoid excessive competition with the grapevines. The soil has a Clay Loam texture in its shallower layers, and a calcic horizon at ca. 60 cm depth (see more details in Table S1).

2. Physiological status and agronomical performance

On July 17th, 2024, leaf water potentials were measured with a pressure chamber (SoilMoisture Equipment Corp., Goleta, CA, USA). Water potential of fully expanded, mature leaves was measured on the same four plants for each of the nine rootstock–scion combinations. Measurements were taken at predawn (Ψ_{pd}, 5:00 AM, local time) and midday (Ψ_{md}, 2 PM, local time). Stomatal conductance (g_s) was measured at mid-morning (11 AM to 12 AM, local time) on 4 to 6 well-sun-exposed, healthy, fully expanded, and photosynthetically active leaves, from the third to fifth node of one of the main central shoots of the plant, using a Li-600 (LI-COR, Lincoln, Nebraska, USA). Agronomic performance was monitored in the 3 plants of each rootstock-scion combination. Plant-level yield was measured as the total fresh weight of berry clusters in each plant at harvest. The total soluble solid content at harvest from berry must (TSS, ºBrix) was determined with a hand refractometer (RBB, OPTECH, Germany). During the following winter, the pruning weight was measured in the sampled plants.

3. Isotopic data: sampling, extraction, and analysis

Isotopic samplings were conducted on two dates: on July 17th, 2024 (*i.e.*, peak summer) at the beginning of the ripening period (BBCH 81) and immediately after harvest on September 9th, 2024 (*i.e.*, harvest), following an abundant late summer rainfall and (BBCH 89-91). Samplings were performed at mid-morning (9 to 11 AM). We selected 3 plants from each of the 9 rootstock–scion combinations. Canes were cut at their base, bark and phloem were peeled off, and the remaining xylem tissue was chopped into smaller pieces that would fit the 12 ml borosilicate glass Exetainers® (LabCo, Lampeter, Wales, UK). Only in the July-peak summer campaign were soil samples obtained by coring the soil with a soil auger attached to an electric-driven breaker HM1400 (Makita Corporation, Anjo, Japan). Three soil cores were obtained from the same rows where plant samples were collected, and soil material was collected from 3 different depths: 0–10 cm, 20–30 cm, and 60–70 cm. The containers with plant and soil samples were closed with a septum cap, wrapped with Parafilm®, and stored in a portable cooler at 4 °C until storage in a laboratory fridge less than 1 hour after the sampling was finished. All samples were shipped in cool boxes to the laboratory where sample water was extracted and analysed following the shipment protocol described by Lehmann *et al*. (2024).

Plant and soil water was extracted from field samples using a cryogenic vacuum distillation (CVD) system following West *et al*. (2006), as precisely described in Diao *et al*. (2022). While δ^2H in CVD-extracted water samples from woody plant material can be biased (Chen *et al*., 2020), plant water source inferences made with $\delta^{18}O$ remain highly reliable (Barbeta *et al*., 2022). After extraction, the δ^2H and $\delta^{18}O$ of water from plants and soils were measured with a high-temperature conversion elemental analyser coupled to a Delta^{Plus} XP isotope ratio mass spectrometer (TC/EA-IRMS; Finnigan MAT, Bremen, Germany). Isotope ratios are reported in permille (‰) relative to Vienna Standard Mean Ocean Water (VSMOW) and measured with a typical precision of 1 ‰ and 0.2 ‰ for δ^2H and $\delta^{18}O$, respectively. In addition, we estimated the monthly mean isotopic composition of meteoric water at the study site using a publicly available machine-learning model (Nelson *et al*., 2021). We downloaded data for the period 2000–2020 and estimated the local meteoric water line (LMWL) as the linear regression between δ^2H and $\delta^{18}O$ in meteoric water. The long-term modelled data were consistent with the rainfall collected and measured between October 2024 and September 2025, after the study period (Figure S3).

4. Data analysis

Ecophysiological, isotopic, and environmental differences among genotypes or other grouping variables were tested with two-way ANOVAs. Rootstock, scion, and the rootstock × scion interaction were fixed factors, and when the overall ANOVA was significant ($p < 0.05$), we conducted TukeyHSD post-hoc tests for pairwise comparisons. For agronomical variables, yield, and pruning weight (but not total soluble solids) were log-transformed to meet the ANOVA's assumptions of normality and homoscedasticity, which were assessed with Shapiro-Wilk and Levene tests on model residuals, respectively. All analyses were conducted using the R package *stats* (R Core Team, 2013).

RESULTS

1. Atmospheric and soil moisture conditions

Environmental conditions are shown in Figure 1. The July-peak summer sampling date encompassed a dry soil (mean VWC 14.7 ± 0.4 % at 30 cm depth) and a hot and relatively dry atmosphere (maximum temperature = 34.9 °C, mean VPD = 1.59 kPa). Compared with July-peak summer, in September-harvest the soil was wetter (VWC = 21.3 ± 3.0 %), and the atmosphere was relatively cooler and moister (maximum temperature = 26.9 °C, mean VPD = 0.67 kPa).

2. Physiological status and agronomical performance for July-peak summer

Rootstocks determined grapevines' exposure to drought, whereas the scions showed contrasting water use. At July-peak summer, leaf water potential at predawn (Ψ_{pd}) did not differ between the three scions ($p = 0.6$) (Figure 2a). In contrast, Ψ_{pd} was significantly lower in the 41B and 140Ru rootstocks compared to 110R ($p < 0.05$, Figure 2d). The interaction of rootstock and scion did not affect Ψ_{pd}. For the midday leaf water potential (Ψ_{md}), Cabernet S presented higher values than Grenache, but differences with Marselan were only marginally significant ($p < 0.05$) (Figure 2b). As for Ψ_{pd}, Ψ_{md} was also higher in 110R, compared to 41B and 140Ru ($p < 0.01$, Figure 2e). In addition, the interaction between rootstock and scion was highly significant for Ψ_{md} ($p < 0.001$). Stomatal conductance measured at mid-morning presented no significant differences among scions, rootstocks, and their interaction (Figures 2c and 2f).

In line with the physiological status, the rootstock affected the vegetative growth primarily, as indicated by pruning weight, whereas the scion governed yield and, to some extent, must quality, as indicated by total soluble solids (TSS) in grapes (Figure 3). Indeed, yield was significantly higher in Grenache and Marselan, compared to Cabernet S ($p < 0.01$, Figure 3a), but it was not affected by the rootstock or the rootstock–scion interaction (Figure 3d). In contrast, the pruning weight was the lowest in the 41B rootstock ($p < 0.05$, Figure 3e) but was not significantly different between scions ($p = 0.096$, Figure 3b). Finally, we found no significant effect of the scion on the amount of total soluble solids ($p = 0.229$, Figure 3c), and the slight differences among rootstocks were not significant ($p = 0.095$, Figure 3f). The rootstock × scion interaction was not significant for Ψ_{pd} and g_s, but was highly significant for Ψ_{md} ($p < 0.001$) (Figure S4). Similarly, the rootstock × scion interaction was not significant for any of the agronomical variables (yield: $p = 0.21$; pruning weight: $p = 0.25$; TSS: $p = 0.27$) (Figure S5).

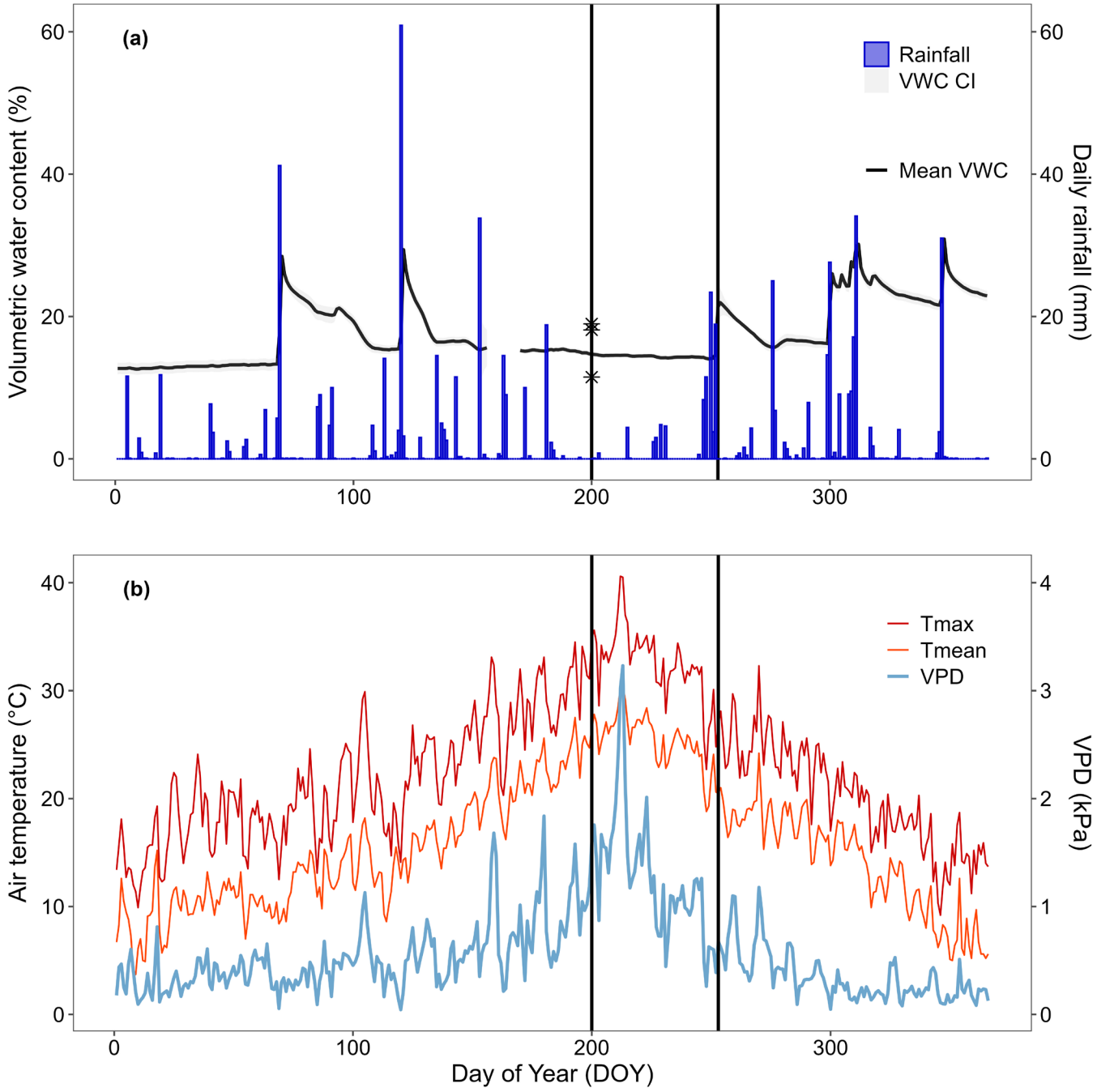


FIGURE 1. Environmental conditions during the study period.

Panel (a) shows the mean VWC at 30 cm (black line, plus the confidence intervals at 95 % in grey) and the daily precipitation amount (blue bars). Panel (b) shows the maximum (red) and mean (orange) daily temperatures and the vapour pressure deficit (VPD) in blue. In both panels, the vertical black lines indicate the date of the two sampling campaigns.

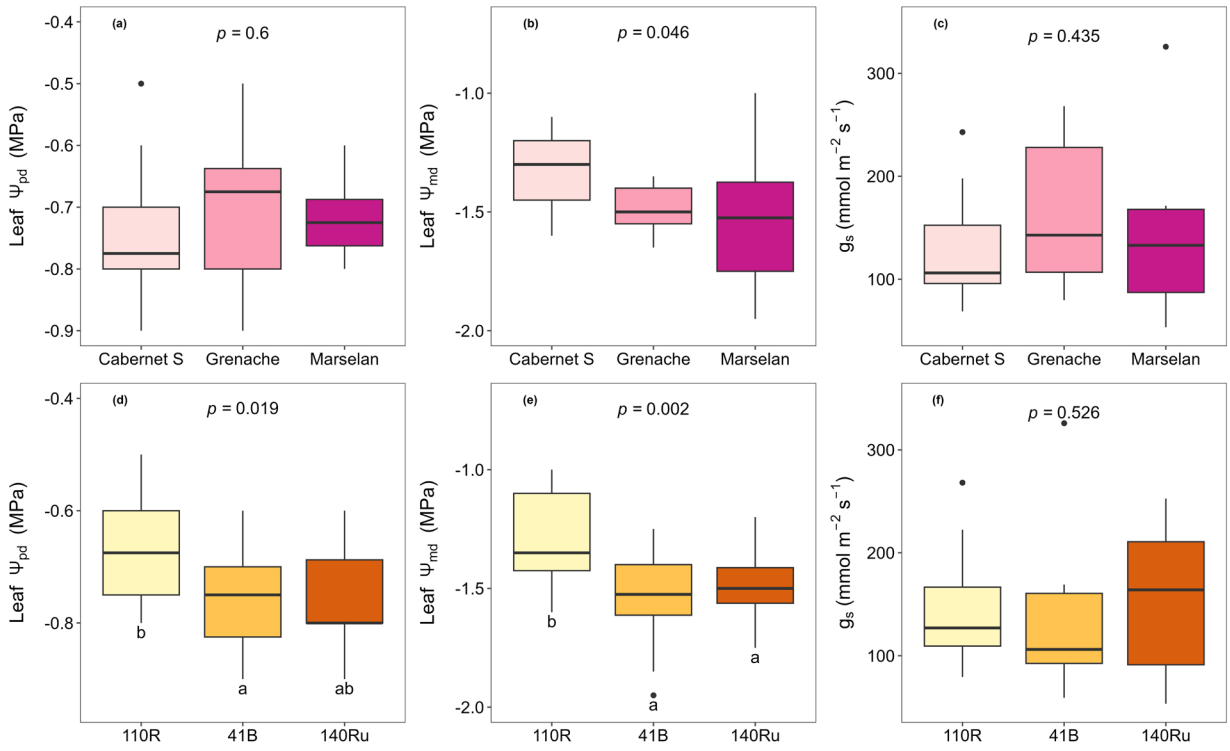


FIGURE 2. Physiological status of grapevine plants in peak summer (July-peak summer).

Top panels (a–c) depict leaf predawn and midday water potential (Ψ_{pd}, Ψ_{md}), and stomatal conductance (g_s) across scions; bottom panels (d–f) show the same variables grouped across rootstocks. Boxes show the median (horizontal line), the interquartile range (box height), data extending 1.5 times the interquartile range (whiskers) and outliers (points). The *p*-value shown in each panel corresponds to an ANOVA test for inter-group differences. If the ANOVA is significant ($p < 0.05$), different letters indicate significant pairwise differences between groups.

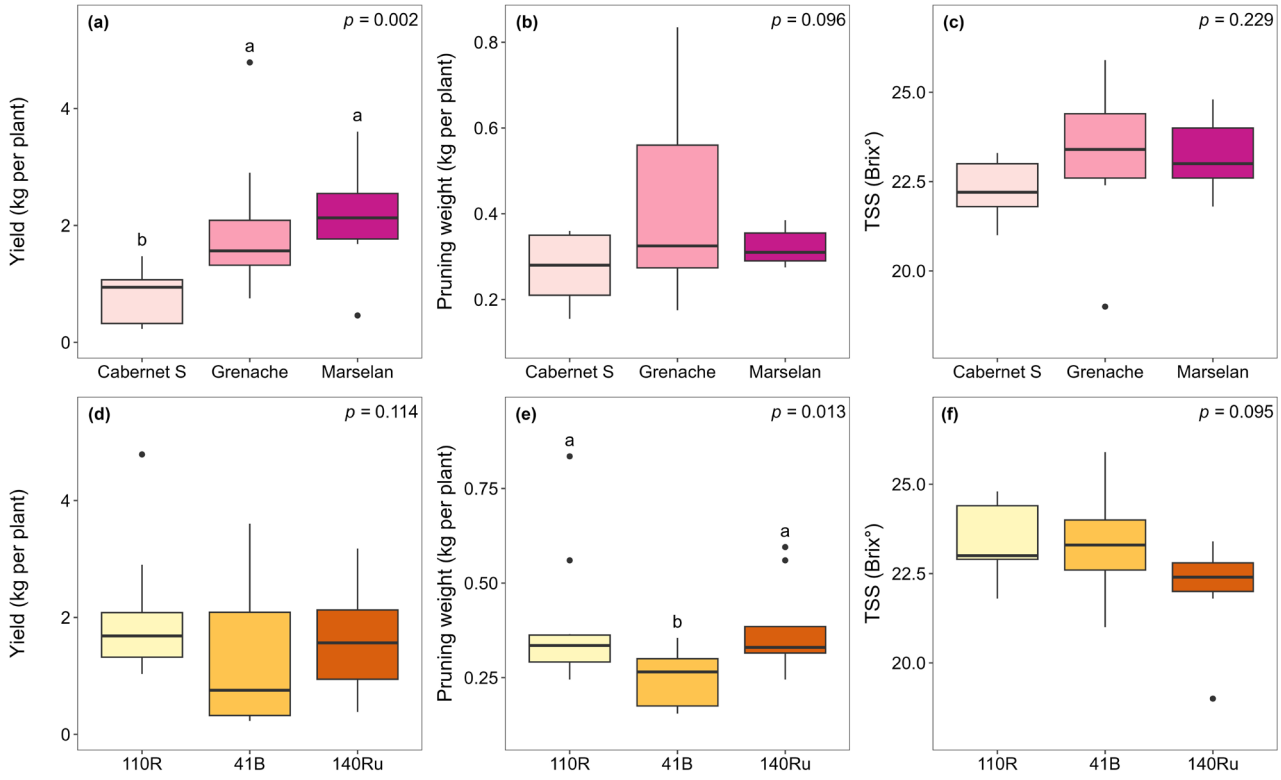


FIGURE 3. Agronomical performance of grapevine plants for the 2024 season.

Top panels (a–c) depict yield, pruning weight and total soluble solids in grapes (TSS) across scions; bottom panels (d–f) show the same variables grouped across rootstocks. Boxes show the same as in Figure 2. The *p*-value shown in each panel corresponds to an ANOVA test for inter-group differences. If the ANOVA is significant ($p < 0.05$), different letters indicate significant pairwise differences between groups.

3. Isotopic-based analysis of grapevine water sources

3.1. July-peak summer

The isotopic composition of the grapevines' water sources in July-peak summer showed a marked isotopic gradient along the soil profile; the isotopic composition was more negative in depth, *i.e.*, more depleted in the heavy isotopes (^{2}H and ^{18}O). Such isotopic contrast in depth was significant for both $\delta^{2}H$ and $\delta^{18}O$ ($p < 0.001$); the shallower layer (0–10 cm) was significantly different from the two deeper layers (Figures 4a and 4b). Importantly, no significant differences in the isotopic composition in $\delta^{2}H$ and $\delta^{18}O$ were found between scions and rootstocks (Figure 4). For this reason, the following interpretations of isotopic data apply to all the studied genotypes. Based on the methodologically reliable $\delta^{18}O$ (Barbeta *et al.*, 2022) of plant water and soil water (Figure 4a), we inferred that the mean depth of root water uptake was located between the shallower soil (0–10 cm) and the deeper layers (> 20 cm). This situation could be given either by plants taking water up from intermediate soil layers, or by plants taking up a mix of sources including both shallow and deep layers. The potentially biased $\delta^{2}H$ (Barbeta *et al.*, 2022; Chen *et al.*, 2020) would indicate a deeper root water uptake (Figure 4b).

3.2. Comparison to September-harvest

In the dual isotope plot (Figure 5), the $\delta^{2}H$ and $\delta^{18}O$ in xylem water for July-peak summer and the September-harvest sampling were compared with modelled meteoric water (*i.e.*, rain, filled circles) and soil water (black squares) in the study site. The plot corroborated that in July-peak summer xylem water (crosses) took an intermediate position between the most enriched soil water samples (top right and below the local meteoric water line) and the average spring rainfall signature (green circles), which coincided with deeper soil water. In contrast, xylem water samples in September-harvest (plus symbols) plotted higher along the local meteoric water line (LMWL), closer to the average isotopic composition of summer rainfall (yellow circles). Still, xylem samples in September-harvest did not plot on the LMWL but between the LMWL and the shallow soil water from July-peak summer.

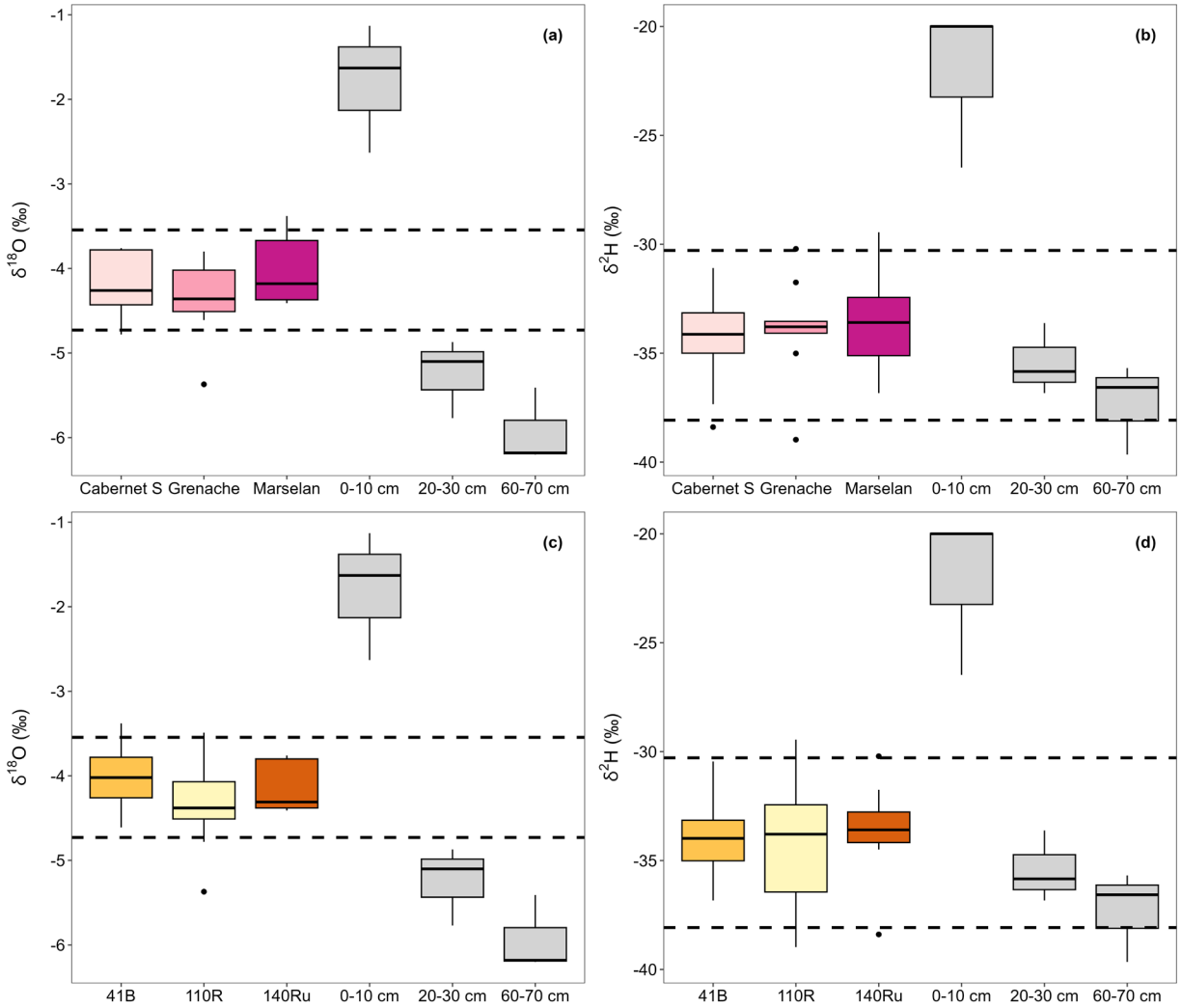


FIGURE 4. Isotopic composition of xylem and soil water in July-peak summer sampling.

Top panels (a,b) show $\delta^{2}H$ and $\delta^{18}O$ across scions, bottom panels (c,d) show $\delta^{2}H$ and $\delta^{18}O$ across rootstocks, and all panels have the soil water in three different depths (grey boxes), all corresponding to the July-peak summer sampling date. Boxes show the same as in Figure 2. The 5–95 % confidence interval for xylem water $\delta^{2}H$ and $\delta^{18}O$ is shown in all panels with a horizontal dashed line.

DISCUSSION

We found significant but slight differences in grapevine exposure to drought between rootstocks growing under the same field conditions, in agreement with previous studies (Zhang *et al*., 2016). The observed differences in Ψ_{pd} in rootstocks but not in scions (Figure 2) suggest that the rootstock 110-R provides grapevines with enhanced access to soil water compared to 140Ru and 41-B. Interestingly, the measured isotopic composition of xylem and soil water (Figure 4) indicates that all rootstocks were extracting water from similar soil depths. Therefore, for the studied rootstocks, differences in access to water do not appear to stem from the ability of certain rootstocks to explore the deep soil, at least under the conditions of this single-season study. This was also found by Alsina *et al*. (2011), who reported a more efficient extraction of water from the same soil layer(s). This improved efficiency of 110-R could be caused by (i) differences in the architecture of the root system, *e.g*., in the root length distribution (Fichtl *et al*., 2025) or in its biomass (Flor *et al*., 2025), (ii) aquaporin-mediated cellular hydraulic adjustment (Sabir *et al*., 2021; Zarrouk *et al*., 2016); (iii) active physiological mechanisms such as osmotic adjustments (Sinclair *et al*., 2024) or (iv) a better root symbiotic association capacity, impacting on the distribution and composition of soil microbial community which may lead to higher level of rhizosphere moisture (Lailheugue *et al*., 2024; Noceto *et al*., 2024; Velaz *et al*., 2025). If drought conditions were more severe than in this study, xylem resistance to cavitation should also be considered (Lamarque *et al*., 2023; Peccoux *et al*., 2018). Multi-scale integrative studies are needed to understand rootstock mechanisms for water extraction in dry soils (Bernardo *et al*., 2025).

Second, we found significant effects of the rootstock on Ψ_{pd} (Figure 2d) (Gambetta *et al*., 2020; Dayer *et al*., 2022) and on whole-season vegetative growth (pruning weights, Figure 3b) (Marín *et al*., 2022). Instead, our results indicate that the scion influences grape yield (Figure 3a) (Buesa *et al*., 2023).

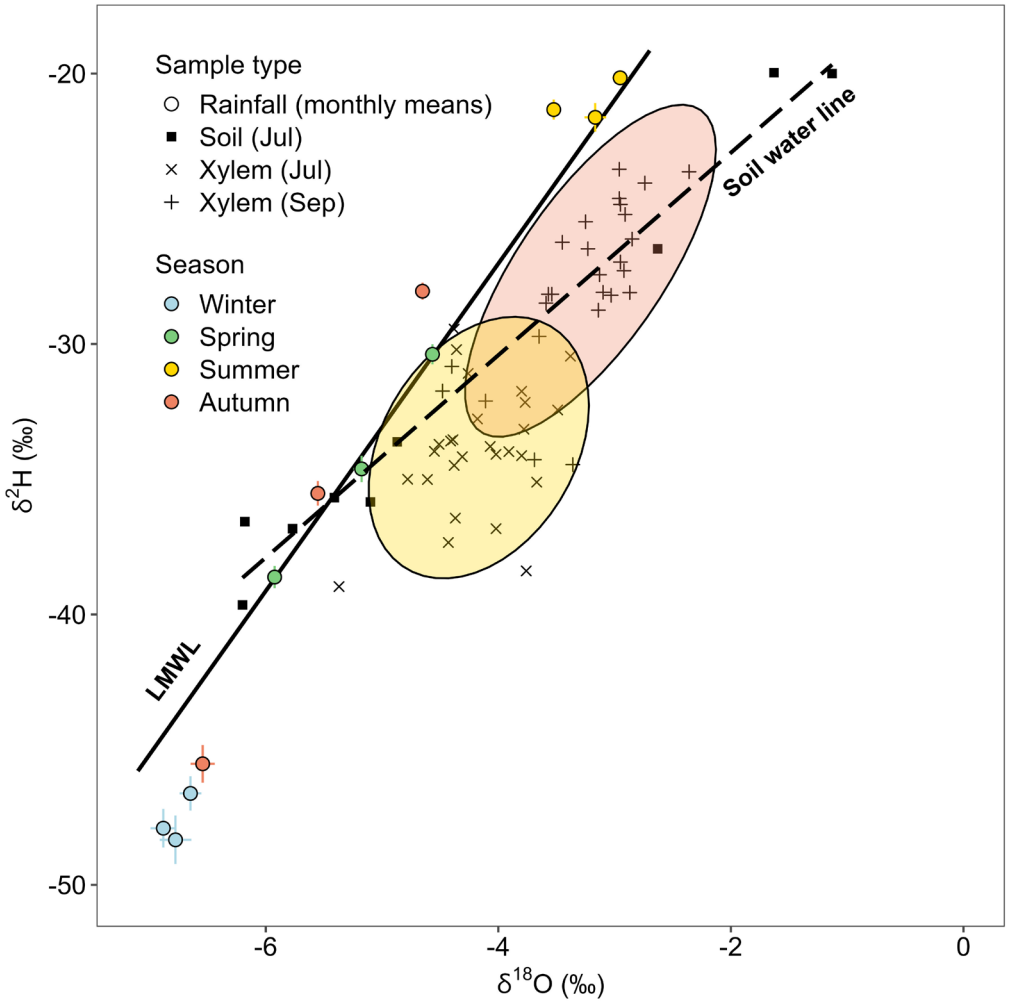


FIGURE 5. Dual isotope plot of xylem, soil, and modelled meteoric water.

The isotopic composition of hydrogen (δ^2H) and oxygen ($\delta^{18}O$) of all analysed water pools is presented together. This includes xylem water from July-peak summer (crosses, x) and September-harvest (plus symbols, +), soil water from July (closed black squares) and modelled meteoric water (filled circles) averaged at a monthly scale, colour-grouped by the season of each month. The solid line corresponds to the modelled local meteoric water line (LMWL), the thick dashed line corresponds to the soil water line (linear regression of soil water samples). Finally, the 95 % confidence ellipse shows the bivariate spread in δ^2H and $\delta^{18}O$ for both sampling campaigns.

The only variable that showed effects of both the scion and the rootstock was the whole-plant water use regulation (Ψ_{md}, Figures 2b and 2e), an integrative measure that may reflect rootstock effects on transpiration (Peccoux *et al*., 2018). Besides Ψ_{md}, we observe distinct significant effects of rootstock and scion on measured variables during the period of study (Barrios-Masias *et al*., 2018), the former being more determinant for Ψ_{pd} and whole-plant growth, and the latter having a stronger effect on yield. Indeed, roots are the key mediator for hydraulic and hormonal signalling that control the physiological responses at leaf level and thereby photosynthetic and assimilate translocation capacities (Chaves *et al*., 2010; Gambetta *et al*., 2020), whereas reproductive components are mainly dependent on the scion's genotype and canopy microclimate conditions (Keller *et al*., 2016). Once water reaches the above-ground organs, there are still scion-specific effects on the water use regulation (Ψ_{md}), which adds to the extensive literature reporting the diversity of responses to drought in commercial *Vitis vinifera* scions (Damásio *et al*., 2025; Dayer *et al*., 2022; Lamarque *et al*., 2023). At first glance, our study encompasses only one growing season and may fall short of capturing the full range of physiological interactions between the rootstock and the scion, as well as their agronomic consequences (but see Figures S4 and S5). However, we provide evidence that in a rainfed Mediterranean vineyard under relatively dry yet average climatic conditions, enhanced water access via drought-adapted rootstocks (*e.g.*, 110-R) does not necessarily translate to higher yields.

Although we observed statistically significant differences in physiological status and agronomical performance between rootstocks and scions, we acknowledge that the limited duration of the study (only one single season with mild stress conditions) and the restricted number of sampling dates and variables monitored do not allow us to robustly disentangle the roles of rootstock and scion and interactions in determining grapevine responses to drought. While our study is motivated by showing the usefulness of stable isotope application in viticulture, we explicitly acknowledge study limitations constraining the strength of our conclusions. First, multi-season studies are needed to corroborate the preliminary results presented here and to cover the complete range of drought conditions experienced in the studied vineyard. Second, physiological measurements were conducted on a single date during peak summer stress, without a baseline under non-stressed conditions. This limits our ability to fully disentangle constitutive rootstock effects on plant water relations from stress-induced responses (Marguerit *et al*., 2012; Simonneau *et al*., 2017). Third, only two isotopic sampling dates were available, which restricts the temporal resolution of the ecohydrological dynamics. However, we note that peak summer conditions represent the optimal timing for isotopic source discrimination, as the isotopic contrast between shallow and deep soil water layers is maximised during this period (Benettin *et al*., 2025). In wet periods, deep water infiltration and mixing processes complicate the definition of isotopically distinct sources, potentially reducing the discriminating power of the isotopic approach (Rothfuss & Javaux, 2017).

Our results also show that root water uptake remains functional in the shallower soil layers after harvest, despite the drier conditions of this layer during summer (Figure 1). The upward shift in the isotopic composition of grapevine xylem water from peak summer to harvest (Figure 5) is likely due to the prompt uptake of late summer rainfall that fell just before the sampling (Figure 1a). The xylem water was then plotted between the modelled isotopic composition of rainfall in summer and the soil water from July to peak summer. We could thus speculate that the roots in late summer are still active enough to quickly take up water (Malheiro *et al*., 2016), which may have consequences on carbon uptake, carbon reserves, and future yield (Smith & Holzapfel, 2009).

To the best of our knowledge, our study is the first to use the isotopic composition of water to conduct field belowground phenotyping of *Vitis* rootstocks. Previous research used this approach to identify the uptake of water from particular sources (Savi *et al*., 2018) and to study vineyards' ecohydrological dynamics in a broad sense (Benettin *et al*., 2025). We build on this existing experience and illustrate how isotopic approaches are also useful for understanding grapevine physiological responses to drought and could potentially inform the development of drought-tolerant rootstock ideotypes (Bernardo *et al*., 2025). Our findings show how isotopic data may contribute to narrowing down the range of explanations for rootstock-specific differences in soil water access and uptake. Thus, isotopic tracers hold a promising potential for viticulture research that may benefit from understanding root water uptake spatiotemporal dynamics. Notably, these include rootstock phenotyping in field conditions, soil management practices related to water dynamics, and optimising irrigation practices.

CONCLUSIONS

We provide exploratory evidence that the rootstock genotype could more strongly influence grapevine exposure to drought, while the scion could determine physiological and agronomic responses to drought. This observation might not be general and should be confirmed by more detailed and long-term studies of grapevine water relations (*e.g.*, Marguerit *et al*., 2012; Simonneau *et al*., 2017). Indeed, the rootstock × scion interaction was significant for midday water potential, highlighting the complexity of grafted plant responses to drought (Figure S4). In addition, we found that rootstock-mediated differences in water use do not necessarily stem from differences in the depth of water uptake, at least during mild drought conditions. This preliminary but relevant finding illustrates the potential of water isotope tracers for field-based rootstock phenotyping in Mediterranean vineyards, complementing classical physiological approaches and contributing to the development of drought-adapted rootstock ideotypes.

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