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Selecting rootstocks to improve vine performance and vineyard sustainability in deficit irrigated Monastrell grapevines under semiarid conditions

Pascual Romero*, Pablo Botía, Josefa María Navarro

Grupo de Riego y Fisiología del Estrés, Departamento de Bioeconomía, agua y medio ambiente, Instituto Murciano de Investigación y Desarrollo Agrario y Alimentario (IMIDA), c/ Mayor s/n, 30150, La Alberca, Murcia, Spain

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ABSTRACT

Regulated deficit irrigation (RDI) and partial root zone irrigation (PRI) were compared for five years, in field-grown mature Monastrell grapevines grafted on five different rootstocks (140Ru, 1103 P, 41B, 110R, and 161-49C), in the semiarid winegrowing region of D.O. Bullas, South Eastern Spain. Vines grafted on invigorating rootstocks (140Ru or 1103 P) showed the highest vigor, water productivity, and productive water use efficiency (WUE_{yield}), but at the expense of berry quality (lower berry quality indices, QI), compared to those on rootstocks of medium-low vigor (41B, 110R, and 161-49C). Vines grafted on 41B showed a moderate vigor-yield-efficiency-quality response, and this did not improve substantially the final berry quality. The least vigorous rootstocks (161-49C and 110R) gave lower yield, WUE_{yield}, and productivity ratios, but a significant improvement in long-term final berry quality. The PRI increased the yield and/or berry quality attributes, especially in low vigor rootstocks (161-49C, 110R) and high vigor rootstocks (140Ru, 1103 P), but not in the medium vigor rootstock 41B. In addition, PRI produced a beneficial increase in the nutraceutical potential for practically all rootstocks. The PRI vines grafted on 161-49C gave the lowest yield and WUE_{yield}, but the highest QI scores and the highest nutraceutical value, while PRI vines grafted on 110R had enhanced long-term yield, WUE_{yield}, and amino acid and resveratrol contents, with similar berry quality (QI) indices, compared to RDI vines. Both 161-49C and 110R seem good options to achieve a compromise between long-term yield-quality-efficiency and returns for the grower. The application of low water volumes (85-90 mm $year^{-1}$) with well-designed DI strategies was enough to maintain the vines in an optimum physiological state, obtaining moderate yields (7,400–9,900 kg ha^{-1}, for 161-49C and 110R) with high berry quality and nutraceutical potential for premium red wine production. Such an approach can serve as an adaptation measure in the face of climate change, to improve vine performance and enhance Monastrell vineyard sustainability under semiarid and water limiting conditions.

1. Introduction

According to the climate projections for the middle of this century (2040–2070), temperature, aridity, and water stress are expected to increase in many areas of southern Europe, reducing yield and growth of the vine (Fraga et al., 2013, 2016; IPCC, 2014; Resco, 2015; Guiot and Cramer, 2016). In addition, the increase in extreme temperatures may lead to an increased risk of pests and diseases (Fraga et al., 2013) and a decrease in quality and yield due to recurrent heat shock, especially in the more continental and warmer areas from the center and south of the Iberian Peninsula. It would be in these semiarid regions of southern Europe (e.g. SE Spain) where viticulture would need to make the greatest efforts of adaptation, with greater costs to maintain quality and productivity, since they are going to experience more severe water stress and impacts of greater magnitude than other wine-growing areas (Resco et al., 2016). In these warm and more vulnerable regions it will be necessary to combine different adaptation measures, especially those related to water management and availability (Iglesias and Garrote, 2015).

Water scarcity is one of the most important problems of agriculture in semiarid regions. Increased aridity and reduced rainfall (predicted in the future) will increase water scarcity, making the availability of water for irrigation an even more limiting factor for agriculture. The predicted increase in evapotranspiration and in the water needs of the vine as a result of climate change (CC) will make necessary the application of irrigation water to maintain the sustainability of vineyards and to

* Corresponding author.
E-mail address: pascual.romero@carm.es (P. Romero).

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Table 1
Mean values of several climatic parameters in different phenologial periods for every year of the experiment in the study area.

Phenological period	Period of the year	ETo (mm)	VPD (kPa)	Rainfall (mm)	Tªmax (ºC)	Tªmed. (ºC)	Tªmin (ºC)	Solar rad. (Wm^{-2})
Year 2012								
Budburst-fruit set	1 April–1 June	281	1.08	30	23.3	16.0	7.3	270
Fruit set-veraison	2 June–31 July	379	1.90	2	32.3	24.3	14.5	321
Veraison-harvest	1 August–24 Sept	272	1.84	9	32.7	24.0	14.3	252
Postharvest	25 Sept–31 Octob.	78	0.61	185	22.4	15.4	9.2	155
Dormancy period	1 Nov–31 March	242	0.39	169	15.2	7.5	0.8	130
Total/annual average		**1,253**	**1.00**	**395**	**22.7**	**14.9**	**6.9**	**209**
Year 2013								
Budburst-fruit set	1 April–1 June	241	0.80	78	21.4	14.5	7.0	249
Fruit set-veraison	2 June– 31 July	355	1.70	4	30.4	22.2	11.6	320
Veraison-harvest	1 August–26 Sept	257	1.29	39	30.3	22.4	14.3	247
Postharvest	27 Ssept–31 Octob.	91	0.94	4	26.3	18.2	10.7	164
Dormancy period	1 Nov–31 March	267	0.50	119	15.4	8.1	1.1	128
Total/annual average		**1,211**	**0.95**	**244**	**22.3**	**14.7**	**6.9**	**206**
Year 2014								
Budburst-fruit set	1 April–1 June	298	1.19	28	25.0	16.9	7.6	274
Fruit set-veraison	2 June– 31 July	361	1.75	8	31.3	23.4	14.3	307
Veraison-harvest	1 August–18 Sept	264	1.80	0	32.9	24.6	15.2	272
Postharvest	19 Sept–31 Octob.	111	0.91	20	25.7	17.9	10.6	162
Dormancy period	1 Nov–31 March	276	0.51	77	16.4	9.0	2.1	127
Total/annual average		**1,309**	**1.06**	**133**	**23.6**	**15.9**	**7.8**	**207**
Year 2015								
Budburst-fruit set	1 April–1 June	266	1.09	24	24.3	16.6	8.2	260
Fruit set-veraison	2 June–31 July	373	2.02	16	33.3	24.6	14.4	312
Veraison-harvest	1 August–18 Sept	227	1.45	79	30.9	23.7	16.5	238
Postharvest	19 Sept–31 Octob.	102	0.73	50	23.7	16.8	10.4	162
Dormancy period	1 Nov–31 March	250	0.46	185	16.5	8.6	2.0	128
Total/annual average		**1,218**	**0.99**	**354**	**23.3**	**15.5**	**8.0**	**201**
Year 2016								
Budburst-fruit set	1 April–1 June	260	0.95	51	22.7	15.5	7.1	256
Fruit set-veraison	2 June–31 July	363	1.96	0	32.0	23.9	13.8	309
Veraison-harvest	1 August–19 Sept	237	1.71	2	31.9	23.5	14.1	265
Postharvest	20 Sept–31 Octob.	96	0.76	31	25.1	17.5	10.6	159
Dormancy period	1 Nov–31 March	254	0.47	301	16.0	9.3	3.0	119
Total/annual average		**1,209**	**1.01**	**386**	**23.0**	**15.6**	**7.8**	**200**

prevent severe stress in many wine regions of southern Spain (Resco et al., 2016). One of the main adaptation measures for the vineyards in these areas will be the implementation of strategies, techniques, and technologies that save water and improve the efficiency in the use and application of irrigation water, without causing a decrease in quality. This future scenario with more recurrent drought phenomena and heatwaves will make it more necessary to apply deficit irrigation (DI) techniques as an adaptation to CC. In addition, to face the risks associated with CC and to achieve environmentally sustainable viticulture, vine growers will also have to carry out other changes and make serious adjustments to their traditional production system. These include - as a measure of adaptation in the medium/longer term - the substitution of plant material by different rootstocks, varieties of vine, or clones of the same variety, selected for their better adaptation to and tolerance of the new climatic conditions (Fraga et al., 2013).

The Monastrell variety, native to the Spanish Levant and the most widespread variety in the South East of Spain, is well adapted to these rigorous and dry climates of high temperatures and recurrent drought cycles, because it has evolved since ancient times in these Mediterranean climates. From a physiological point of view, this variety possesses interesting characteristics of drought tolerance, which give it a high capacity to adapt to seasonal water stress and DI strategies (Romero et al., 2010, 2012, 2014). In this respect, we have verified that DI techniques, such as regulated deficit irrigation (RDI) and partial root-zone drying irrigation (PRI), efficiently applied and using moderate annual volumes of water, maintain high yields and improve long-term water use efficiency (WUE) and berry and wine quality in Monastrell wine grapes under semiarid conditions (Romero et al., 2016a, 2016b).

The choice of more efficient and drought tolerant rootstocks has been proposed as another measure of adaptation to CC (Fraga et al., 2013; Berdeja et al., 2015). Genotypic differences in the vigor of the rootstocks induce morphological and anatomical modifications and changes in the distribution of the root system, which may influence the soil volume explored and the availability of water to the plant. In this way, the rootstock can affect the regulation of water relations, (Alsina et al., 2011; Jones, 2012), yield components and fruit composition (Berdeja et al., 2014; Habran et al., 2016).

In a warm winegrowing area of the Jumilla Region (SE Spain), Monastrell vines grafted on an invigorating rootstock (e.g. 1103 P, classified as a rootstock with medium-high drought tolerance and widely used in this area) responded well to the application of different DI techniques - such as PRI and RDI - with moderate amounts of water, the optimum irrigation being 140–150 mm $year^{-1}$ (Romero et al., 2016a, 2016b). Besides, previous results indicate that distinctive PRI effects (compared to RDI) depend on the volumetric soil water content of the wet root zone (Romero et al., 2012), and that the maintenance of a high water content in the wet root zone during drying-re-watering cycles is critical to improve root-vine performance in long-term PRI wine grapes (Romero et al., 2014, a,b).

Nevertheless, we do not know if this agronomic response can be extrapolated to other soil-climatic conditions and, besides, little is known about the interaction of Monastrell with other rootstocks (of differing vigor and drought tolerance) and with DI techniques such as PRI and RDI, justifying the need for further studies in other climatic conditions, with different rootstocks, DI strategies, and water volumes. Thus, the main goal of this study was to determine if the choice of the rootstock modifies substantially the physiological and agronomic