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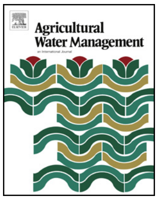

Combined effects of irrigation regimes and crop load on 'Tempranillo' grape composition

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ABSTRACT

The effects of different irrigation regimes, maintained during fruit set to post-harvest (rainfed vines and vines irrigated at 25, 50 and 100% of estimated crop evapotranspiration), were investigated during four consecutive seasons (2005–2008) in a vineyard located in south-western Spain on grapevine cv. Tempranillo berry composition. In addition, two crop level regimes were established for each irrigation treatment by cluster thinning carried out around veraison in a split-plot design with irrigation as the main factor and cluster thinning as second. Considerable vintage-to-vintage variations in many quality parameters were observed despite berry total soluble solids content remaining nearly constant at around 23 °Brix each year. Irrigation applications, when compared with rainfed cultivation, increased berry titratable acidity and malic acid but slightly decreased berry total polyphenols and anthocyanins potential. Veraison cluster thinning increased berry malic acid, potassium and total phenolic compounds but reduced titratable acidity. High crop level slightly delayed harvest date around three days, but grapes from both thinned and unthinned vines reached similar sugar concentrations in all seasons except when leaf area-to-yield ratio was lower than 1 $m^2\,kg^{-1}$, where sugar berry concentration was below 21 °Brix. It is concluded that irrigation is an interesting technique to increase berry titratable acidity for Tempranillo grapes in semi-arid terroirs where grape acidity is usually too low. Cluster thinning can be used to increase berry phenolic potential. However, in addition to the detrimental effects on performance, cluster thinning may decrease the acidity levels. It is therefore only recommended when very high yield hinders proper ripening.

1. Introduction

Irrigation is used in winegrape production regions throughout the world to manage vegetative and reproductive growth and to control berry composition (Fereres and Evans, 2006). A water deficit during berry growth reduces yield and is usually considered beneficial for wine quality, in particular for red wines (Matthews and Ishii, 1990). However, vine response to water supply might vary among winegrape species as well as among cultivars within *Vitis vinifera* L. (Bota et al., 2001; de Souza and Maroco, 2005; Gibberd et al., 2001; Intrigliolo and Castel, 2008; Winkel and Rambal, 1990).

In many Spanish regions and especially in Extremadura (south-western of Spain) the climate is semi-arid, characterized by a dry and warm growing season and a high solar irradiation regime. Irrigation is therefore often used in this region to increase grape yield, as well as in the DO (Denominación de Origen—Certificate of Origin) vineyards to ensure proper maintenance of vine canopies (Royal Decree 170/2009), because of the low rainfall during the growing season and the high evaporative demand.

It is also widely acknowledged that crop level is a determining factor in berry quality and one of the goals of modern viticulture is to establish field practices which are able to limit vineyard yield and improve grapevine composition (Gatti et al., 2012; Palliotti et al., 2011).

However, previous studies, mostly carried out on cv. Cabernet Sauvignon, have shown that a decrease in yield is not necessarily associated with significant changes in grape quality (Bravdo et al.,

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1985; Keller et al., 2005) and that the final effects on wine quality depend on the timing and intensity of the crop level regulation (Chapman et al., 2004). In this respect, while some studies have reported that cluster thinning increased berry sugars and anthocyanins concentration (Guidoni et al., 2002), others have concluded that this effect is slight or non-existent (Keller et al., 2008, 2005; Ough and Nagaoka, 1984). This diversity of results suggests that the effects of cluster thinning depend on soil, climate and genetic factors and possible variations in implementing this practice.

Tempranillo is the most common variety of red grape in Spain comprising a total of 205,975 ha (20% of Spain's total vineyard area), though most of these are cultivated under rainfed conditions with typically low yields ($\leq$6500 kg ha^{-1}). Some studies have investigated the combined long-term impacts of deficit irrigation and cluster thinning in this variety (Gamero et al., 2014; Intrigliolo and Castel, 2011; Santesteban et al., 2011) but no study has considered such a wide range of water regimes in combination with late cluster thinning. This information is needed to determine the optimal level of vine water stress and crop level for optimizing Tempranillo grape composition in semi-arid climatic conditions.

This study investigates the combined effect of different percentages of water replacement based on crop evapotranspiration (ET_c) and two crop level regimes adjusted by cluster thinning at veraison and their interactions on grape quality characteristics in cv. Tempranillo during four growing seasons and under semi-arid weather conditions.

2. Materials and methods

2.1. Site description and field determinations

The experiment was carried out across four consecutive growing seasons (2005–2008) in Extremadura (south–western Spain; lat: 38°51′38″N; long: 6°40′0″W; altitude 198 m) in a cv. 'Tempranillo' vineyard (*Vitis vinifera* L.) with vertical shoot positioning (VSP). The vineyard was planted in 2001 on Ritcher-110 rootstock at a spacing of 2.5 by 1.2 m (3.333 vine ha^{-1}). Vineyard soil had a silt-loam texture with 37.3% sand, 25.5% clay, 6.1% silt and 1.1% of organic matter (average depth 0.0–1.6 m).

The experimental design was a split-plot with four replicates; irrigation being the main factor and crop level the second factor within each irrigation regime. The irrigation treatments were comprised of rainfed vines (no irrigation applied) and vines irrigated at different percentages (25, 50 and 100) of estimated ET_c to induce differences in vine water status. ET_c was estimated as the product of reference evapotranspiration (ET_0), calculated with the Penman–Monteith methodology, and a crop coefficient (K_c). In 2005 and 2006, the K_c values used were based on the methodology of Allen et al. (1998), and in 2007 and 2008 they were obtained as the ET_c/ET_0 ratio. ET_c was measured following the method described in Yrissarry and Naveso (2000), using a weighing lysimeter installed in the experimental plot in 1995 and the same two grape vines as since 2001 when the vineyard was planted on the plot. More details about lysimeter data collection and vine water use are reported in Picón-Toro et al. (2012). Irrigation was applied with pressure-compensated emitters of 4 L h^{-1} placed in a single row 60 cm apart. Irrigation was initiated in all treatments when stem water potential (SWP) reached −0.8 MPa. The total water applied in each treatment and the number of days of the irrigation season are shown in Table 1. Two crop levels were established at veraison for each irrigation regime, un-thinned (high crop level, H) and thinned (low crop level, L), based on leaving a single cluster per shoot.

Phenological stages were determined weekly using Eichhorn and Lorenz (1977) values. Growing degree days (GDD; base 10 °C) from 20 March to 15 December were calculated using data from a weather station located at 50 m distance from the experimental vineyard. Stem water potential (SWP) determinations were performed weekly at midday (13:00–14:00 h) using a pressure chamber (Model Soil Moisture Corp., Santa Barbara, CA, USA) on two leaves of different plants per replication (eight leaves per treatment). Average SWP growing season values are described in this study (for more details of seasonal vine SWP evolution see Uriarte et al., 2015). The experimental plot consists in six rows with 18 vines per row. Yield weight at harvest was determined on ten marked vines per experimental plot and berry weight was determined as the weight of 100 berries from representative field samples of 250 g per replication. Leaf area-to-yield ratio (LA:Y) was also calculated to express the vine sink–source balance using veraison-harvest average LA. LA was determined using a LAI-2000 plant canopy analyzer (LI-COR Inc., Lincoln, NE), measuring two vines per experimental plot (eight vines per treatment) weekly. Mechanical shoot topping, a common practice in the study area, was carried out at the same canopy height for all treatments between fruit set and veraison.

2.2. Must composition

Berry sugars and acid composition were determined weekly from veraison to post-harvest (one week after harvest) in samples of 250 g per experimental plot and treatment (a total of 4 independent samples per treatment and week) from different vines that were used to determine yield weight for each experimental plot. Total soluble solids (TSS) was determined by refractometry (Atago RX-1000 refractometer). Juice pH and titratable acidity (TA) were determined with an automatic titrator (Crison Micro TT) following official methods of the OIV (1990) using a Crison Micro pH-meter (Barcelona, Spain). Titration was carried out with a 0.1 N solution of NaOH to an end point of pH 8.2. Potassium (K+) was determined using a Varian AA 240 FS spectrometer (California, USA) following official methods of the OIV (1990).

Malic acid was determined using the enzymatic method (EEC, 1990) and tartaric acid with the Blouin method (Blouin, 1992). Both acids were analysed in a SYSTEA Easychem Automatic Multidetector (Gomensoro, Madrid). Total polyphenol potential (TPP) was determined following the methodology described by Ribéreau-Gayon et al. (2006). Total anthocyanin potential (TAnP) was quantified in accordance with di Stefano and Gentilini (2002). Both

Table 1
Water balance. Seasonal: rainfall, reference evapotranspiration (ET_0), crop evapotranspiration (ET_c) and average crop coefficient (K_c) from April to September. The duration of the irrigation season and irrigation water volumes applied in each treatment during 2005–2008 growing seasons are shown.

	Seasonal				Irrigation (mm)			
Year	Rainfall (mm)	ET_0 (mm)	ET_c (mm)	K_c	Irrig. days	$25ET_c$	$50ET_c$	$100ET_c$
2005	76	1039	373	0.35	82	56	111	222
2006	116	1024	354	0.31	120	81	161	323
2007[a]	242	975	508	0.52	85	62	137	172
2008	307	1026	755	0.74	103	153	305	611

[a] In 2007 and 2008, crop evapotranspiration (ET_c) values were obtained with a weighing lysimeter installed in the vineyard; see Picón-Toro et al. (2012) for details.