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Modern viticulture in southern Europe: Vulnerabilities and strategies for adaptation to water scarcity

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ABSTRACT

Water is now considered the most important but vulnerable resource in the Mediterranean region. Nevertheless, irrigation expanded fast in the region (e.g. South Portugal and Spain) to mitigate environmental stress and to guarantee stable grape yield and quality. Sustainable wine production depends on sustainable water use in the wine's supply chain, from the vine to the bottle. Better understanding of grapevine stress physiology (e.g. water relations, temperature regulation, water use efficiency), more robust crop monitoring/phenotyping and implementation of best water management practices will help to mitigate climate effects and will enable significant water savings in the vineyard and winery. In this paper, we focused on the major vulnerabilities and opportunities of South European Mediterranean viticulture (e.g. in Portugal and Spain) and present a multi-level strategy (from plant to the consumer) to overcome region's weaknesses and support strategies for adaptation to water scarcity, promote sustainable water use and minimize the environmental impact of the sector.

1. The wine grape industry in south Mediterranean Europe

World's wine production are located in a wide geographical and climatic range, often in mid-latitude regions characterized by climate variability and stressful environments, such as the Mediterranean region (Fraga et al., 2013; Lionello et al., 2014). The European Union (EU-28), is the world's leader in wine production with about 50% of world's vine-growing area and about 60% of total volume of production (USDA, 2014). France, Italy, Spain, Germany and Portugal are the five leading EU wine producers and altogether they represent 90% of EU production (USDA, 2014). Spain has the largest vineyard area in the world (950,541 ha in 2014) with an increasing irrigated area (36% of the total, in 2014) (MAGRAMA, 2014) (Fig. 1). Portugal is the EU's 5th largest wine producer with a total of 6.7 Mhl in 2013 and it has a cultivated area estimated to be about 224,000 ha (IVV, 2015). In 2010, the irrigated area was estimated in 15% of the total area of vineyards (INE, 2010). However, irrigation continued expanding in the recent years in Portugal, in particular in the Alentejo region, and presently, the percentage of irrigated vines should be slightly higher and around 20%. Mediterranean fresh water resources are under high pressure due to fast-growing population, increased water scarcity, extreme climate variability and intensive water use in agriculture, industry and tourism activities (Lange et al., 2005; Costa et al., 2007; EEA, 2012a,b; Lereboullet et al., 2013a,b; Blum, 2014). Water is now considered by EU experts as the most important but vulnerable resource in the Mediterranean region (EU-ERANETMED, 2014). In addition, climate scenarios for South Mediterranean Europe are not favourable for agriculture. The predicted lower precipitation, higher air and soil temperatures, more frequent and longer extreme climate events (e.g. heat waves, extreme drought) (IPCC, 2013) will negatively affect viticulture in the region (Chaves et al., 2010; Rogiers and Clarke, 2013; Teskey et al., 2014; Lionello et al., 2014).

In Europe, irrigation of vineyards is below 10% of the total area, but the tendency towards irrigation is increasing to mitigate the effects of climate change and more stressful environment. Irrigation has therefore expanded in dry regions of France, Spain, Portugal and Italy (Intrigliolo and Castel, 2008; Seguin, 2010; USDA, 2013; Fraga et al., 2013; Barisan et al., 2014; De Leo et al., 2015). Meanwhile, agriculture in South Mediterranean Europe is increasingly subjected to more restrictive legislation at both EU and individual country levels namely in terms of water use regulation and water conservation. Next we present some of the major

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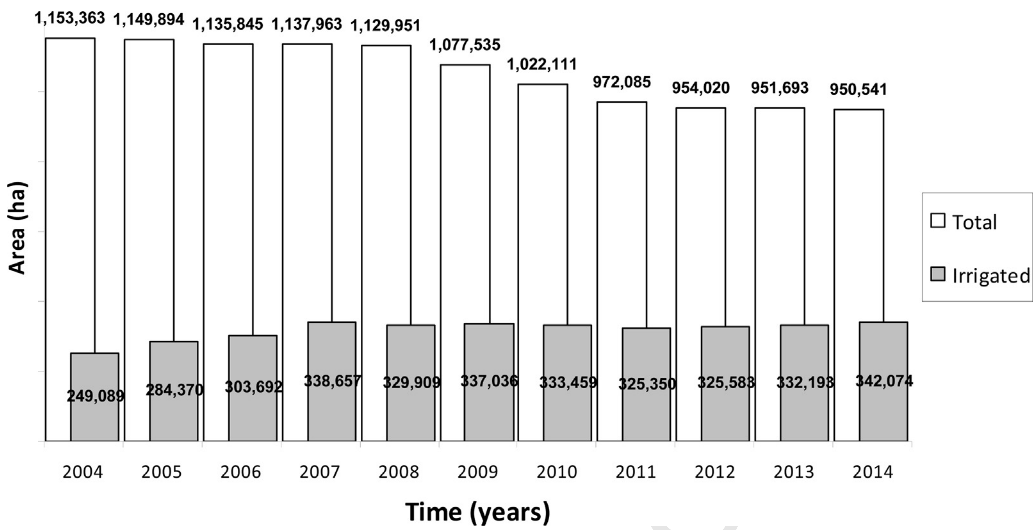

Fig. 1. Total cultivated area (ha) and irrigated area (ha) of Spanish vineyards from 2004 to 2014.
Source: "Encuesta sobre Superficies y Rendimientos de cultivos en España, ESYRCE, Spanish Agriculture Ministry 2014.

constrains and opportunities experienced by South European wine industry, focusing on Spain and Portugal.

1.1. *Constraints (environment and socio-economic)*

An important vulnerability of rainfed agriculture in the Mediterranean is the combination of high air temperature and water deficit coupled to marked inter-annual and intra-annual climate variability and scarce water resources (Costa et al., 2007; Lopes et al., 2014; Rogiers and Clarke, 2013; Valverde et al., 2015). In the case of *Vitis vinifera*, Mediterranean climate may limit yield and berry quality because most of the berry growth and ripening period occurs under conditions of high air temperature and soil water deficit (Medrano et al., 2003; Chaves et al., 2007, 2010; Lereboullet et al., 2013a,b; 2014). In rainfed Mediterranean viticulture, water stress can be particularly severe during summer mainly if previous winter and spring seasons are dry just. This situation is often reported for the Mediterranean zones of the Iberian Peninsula (e.g. Alentejo wine region in years 2003 and 2005). Moreover, Mediterranean viticulture is increasingly exposed to climate extremes (e.g. maximum temperatures and heat waves) (EASAC, 2013; Fraga et al., 2013; Hannah et al., 2013; Lereboullet et al., 2013a,b; Lionello et al., 2014). Not only extreme air temperatures but also high soil temperatures can be potentially negative for berry and leaf/canopy physiology. In fact, soil temperature (T_s) in Southern European countries can easily reach values above 50 °C along the day (Fig. 2). High soil temperature not only influences root activity and root growth but also negatively impacts leaf/canopy photosynthesis, as well as diurnal and nocturnal stomatal conductance (Rogiers and Clarke, 2013). Temperature determines berry composition and quality by influencing the ripening process, berry biochemistry and synthesis/degradation of certain compounds such as anthocyanins or polyphenols (Mori et al., 2007; Teixeira et al., 2013; Zarrouk et al., 2014). High berry temperatures (>35 °C) may inhibit anthocyanins synthesis and induce their degradation (Bergqvist et al., 2001; Spayd et al., 2002).

Portugal is relatively well endowed in terms of water resources. However, these resources are unevenly distributed with marked difference between the rainy and cooler North and central Atlantic regions of the country and the dry and warmer South, inland regions (e.g. Alentejo). The same occurs with Spain which presents large differences in terms of water reserves and precipitation between the Atlantic and Northern regions and the southern Mediterranean regions. In Portugal, irrigated viticulture expanded mostly in the southern part of the country (Península de Setúbal, Alentejo, Algarve) but now other wine regions (e.g. Tejo, Douro Superior) are also now being punctually irrigated to face more stressful summer conditions (Fraga et al., 2013; Lopes et al., 2014). Spanish vineyards have been traditionally dry-farmed because irrigation was forbidden by law until 1996. Nowadays, irrigation is still not permitted in most of the "Denominaciones de Origen (DO)", and just like in Portugal, irrigation is only allowed under specific circumstances and after the technical allowance from Regional wine Commissions. However, vineyards in areas out of the DO control can be irrigated without any restriction. Although irrigation has increased dramatically in Spanish viticulture (Fig. 1), there are still authors questioning whether this is an environmentally sustainable trend in semi-arid areas such as regions of central and southern Spain (Intrigliolo and Castel, 2008; Romero et al., 2010; Medrano et al., 2015).

Ground water resources in the Mediterranean also deserve more attention. Indeed, they contribute to 20–100% of the water used in European irrigated farms, depending on the region and country. Besides the ongoing climate change is expected to limit recharge of aquifers due to reduced precipitation and to increased water abstraction to support larger irrigation needs and to minimize the problem of lower quality surface waters (Costa et al., 2007; Goderniaux et al., 2009; Stigter, 2012; Baudron et al., 2014; Carreira et al., 2014). Also, in most of the EU countries, groundwater users pay no tariff to water authorities and only few countries (France, Netherlands, Denmark, England and Wales) do charge a water abstraction fee (OECD, 2010).

Vulnerability and adaptive capacity of the Mediterranean viticulture is also linked to socio-economical aspects (Strano et al., 2013; Lereboullet et al., 2012; 2013a,b). For example, the small size of most of the companies results in limited budgets and restricted innovation with limited capacity to accommodate new legislation requirements for environment or new market trends related to quality (ECOPROWINE, 2014). In addition, fluctuations in the wine markets poses a limitation to Mediterranean viticulture and affect mostly smaller companies. Another limitation is the lack of information and perception of risks by growers and managers of smaller companies which restrict changes in terms of adoption of novel agronomic strategies or technologies to mitigate climate change and respond to changes in consumer demand and to more restrictive legislation on water use.

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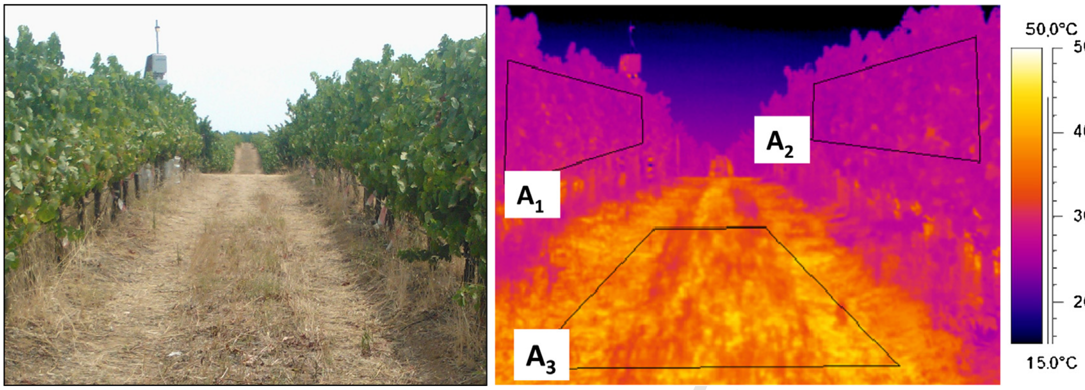

Fig. 2. Visible (on the left) and false colored IR thermal image (on the right) from two rows and the inter row (3m wide) of 12 year-old vines of the variety Aragonez (Syn. Tempranillo), in a commercial vineyard, in Reguengos de Monsaraz, southern Portugal (38°23′55.00″N, 7°32′46.00″W). Measurements were done at around 14.30 h on 24 July 2014, by using a Flir ThermaCAM B20, 240 × 320 pixels (ϵ = 0.96) under the following environmental conditions: T_{air} = 28.3 °C, Air RH = 40%, VPD = 2.8 KPa; Wind speed = 2.8 ms^{-1}; Global radiation = 800 Wm^{-2}. Temperature of selected area 1 (A_1) (Tc sunlit side) = 27.4 ± 1.1 °C, Temperature of selected area 2 (A_2) (Tc shadow side) = 26.8 ± 1.1 °C, Temperature of selected area 3 (A_3) (soil surface) = 37.1 ± 2.5 °C.

The lack of labour force can also be a problem in certain Mediterranean wine regions and therefore the use of emigrant labour force became common in Spain, Portugal or France following the trends observed in other intensive production agricultural systems (greenhouse horticulture) (FAO, 2013; Costa et al., 2014). Lack of statistical information concerning water use and management in the Mediterranean hinders proper policy decision on aquifer management, irrigation, pollution emissions from either surface or subsurface (Albiac, 2005; EEA, 2012a). In fact, we may still find data collections and assessments with large data gaps, lack of harmonization in estimation and data quality assurance methodologies (EEA, 2012a).

1.2. Opportunities

Regarding the opportunities for Mediterranean viticulture, the large historical and cultural relevance of the crop and related activities is particularly visible in Spain and Portugal, where the crop is being cultivated for centuries. This results in a large cultural tradition, available empirical knowledge, variety selection and large diversity of autochthonous varieties (Tapia et al., 2007; Gonçalves and Martins, 2015; Fraga et al., 2015). Portugal has a large genetic variability which has been stored in a network of both commercial and public vineyards. Recent set of actions were taken by the Portuguese Association for Grapevine Diversity (PORVID) to safeguard such genetic heritage and organize Portuguese biodiversity. A prospection and conservation project has been carried out with the principal objective of building a full-diversity in vivo library of the Portuguese grapevine heritage (Martins, 2011; Gonçalves and Martins, 2015). Similarly over the last few years, many regions of Spain have developed several projects focused on the prospection, characterisation and conservation of autochthonous varieties. The “Instituto Madrileño de Desarrolo Agrario” (IMIDRA) takes care of the official ampelographic collection of grapevines in Spain, and coordinates most of these projects.

The production of premium and super-premium wines give an Iberian viticulture a competitive advantage over other worldwide competitors. The multiplicity of genotypes and “terroirs” makes the Iberia Peninsula a unique region for wine production and has generated a large number of high quality vintage wines that had won several accolades worldwide. The multiple South European Mediterranean “terroirs” (e.g. Vinhos Verdes, Douro, Dão, Alentejo, Rias Baixas, Rioja, Ribera de Duero, Balearic Islands) and specific varieties (e.g. the Touriga Nacional, or the “Tempranillo”) make it possible to create unique monovarietal wines or novel blends with particular tastes and aromas, which gives major competitive advantage to the Mediterranean wine sector.

Wine industry is one of the most innovative sub sectors of the EU agribusiness and there is a strong commitment of the EU translated into major investments in research and technology with a clear focus on sustainable viticulture. This is the case of major EU financed projects related to the wine sector such as EU-INNOVINE or ECOPROWINE. Additionally, cooperation between the Universities and private companies is also being promoted by EU projects. In parallel, Portuguese and Spanish authorities are promoting the image of Iberian wines abroad which permitted to increase exports and guarantee higher financial income for both countries (USDA, 2013; MAGRAMA, 2014; IVV, 2015). Finally, the increase in multiple and more demanding export markets is putting pressure on Portuguese and Spanish wine industry forcing local vineyards and wineries to a higher commitment on more environmentally sustainable practices, similarly to what is occurring in other important wine regions worldwide (Sinha and Akoorie, 2010; Berghoef and Dodds, 2011; CWSA, 2011; Retallack 2012, 2013; Gerling 2015; De Leo et al., 2015; Radke et al., 2015) or to other horticultural commodities (Torrellas et al., 2013; FAO, 2013).

2. Advances in the understanding of grapevine responses to heat stress and drought

2.1. Stomata, leaf temperature and water use efficiency

Tolerance/resistance to drought and heat stress involves combination of several traits and mechanisms that can be morpho-anatomical, physiological and hydraulic (Chaves et al., 2010; Carvalho et al., 2015). Understanding the physiology and biochemistry related to stomatal regulation and their response to abiotic stress (e.g. drought) is crucial to understand plant responses to the environment and to improve plant water relations and WUE (Roelfsema and Kollist, 2013; Tsegay et al., 2014). Besides, stomatal regulation in grapevine varies with the genotype (Costa et al., 2012; Tomás et al., 2014a) and identically, we find large intra-specific variability for intrinsic WUE (Bota et al., 2001; Gaudillère et al., 2002; Koundouras et al., 2008; Rogiers et al., 2011; Tomás et al., 2012).

Improved WUE can result in water savings at both plant and crop levels, but scaling-up from single leaves to crop is not a straightforward process (Medrano et al., 2015). In fact, previous research showed that improvements in leaf-level WUE may not always translate into higher crop WUE or higher yield (Condon et al., 2004). Actually, WUE is a complex multi-trait phenotype related with stomatal control and also with leaf structure, leaf biochemistry and leaf diffusive properties (e.g. mesophyll conductance) (Tomás et al., 2014b; Gago et al., 2015). Differences in WUE behaviour between grapevine genotypes/varieties depend on other traits such as hydraulic and hormones as reported for model and crops species (Matzner and Comstock, 2001; Pantin et al., 2013; Torrez Ruiz et al., 2014).

In parallel with studies on WUE, a better comprehension of how plants regulate their leaf/canopy temperature in relation to stomatal behavior is equally relevant to improve adaptation/resistance to longer periods of heat and drought stress. Grapevine is considered a drought resistant species due to an efficient control of stomatal aperture in response to soil and air water deficits (Chaves et al., 2010; Costa et al., 2012). This behavior can be a protective strategy against excessive water loss and xylem cavitation (Chaves et al., 2010; Lovisolo et al., 2010) but such stomatal phenotype can also result in reduced evaporative cooling and consequent abnormal increase of leaf temperature (T_{leaf}) under extreme conditions (high air temperatures and soil water deficits). In fact, under typical South Europe Mediterranean conditions (e.g. Alentejo Portuguese wine region, South Portugal), canopy temperatures can easily reach values largely above the range considered optimum for grapevine photosynthesis (25–30 °C) (Costa et al., unpublished results). Extended periods of supra-optimal temperatures can give rise to damage in the photosynthetic apparatus with negative effects on WUE (Sinclair et al., 1975; Tambussi et al., 2007). According to Sinclair et al. (1975) this may occur via: (1) an increase in transpiration due to the exponential increase in saturated water vapor density inside the leaf that increases water vapor gradient between the leaf and the outside air; (2) an increase in leaf respiration rates as T_{leaf} increases, with negative effect on net CO_2 assimilation. Tambussi et al. (2007) states that for cereal crops a potential gain in instantaneous WUE ($WUE_{instantaneous} = A_N/E$) at leaf level may be less marked when the decrease in stomatal conductance to water vapour is linked to higher T_{leaf} and thus increased transpiration per stomatal conductance unit (Condon et al., 2002). Tambussi et al. (2007) also states that an increased T_{leaf} could induce penalties in yield and eventually in WUE_{yield} in situations where evaporative cooling effect of transpiration is important (Reynolds et al., 2001). Therefore, higher T_{leaf} and boundary layer effect may pose limitations to the 'scaling-up' of WUE from leaf to crop level. For instance, it has been pointed out that modern irrigation systems in which mild to moderate water stress is applied (improving WUE by partial stomatal closing) could have a lower effect than expected in crops with dense canopies (Kang and Zhang, 2004), this can partly apply in the case of *V. vinifera*.

Finally, high T_{leaf} can result in accelerated leaf senescence with accelerated leaf abscission, which in the case of grapevines grown in hot climates could end in quality and yield losses due to overexposure of berries to light. Therefore, breeding and selection of grapevine for typical Mediterranean semi-arid conditions should focus on a compromise between high WUE and leaf cooling (Chaves et al., 2010; Costa et al., 2012).

2.2. Morpho-hydraulics and water transport

Leaf hydraulics is a key component of plants adaptation strategy in response to the environment. Recent studies in grapevine showed that hydraulic conductivity of leaves (K_{leaf}) and of stem (K_{stem}) contributes to variation among varieties regarding their response to soil water deficit and the recovery response to drought (Schultz and Stoll, 2010; Coupel-Ledru et al., 2014; Hochberg et al., 2015; Martorell et al., 2015). The observed intra-specific variation in K_{leaf} can reflect differences in leaf morpho-anatomy (Nardini et al., 2012) and in water pathways through the outside xylem to the water evaporation sites. Contrary to water transport systems, leaf vein systems show great variation in arrangement, density, vascular bundle features and xylem conduits within the bundles (Sack and Scoffoni, 2012). In grapevine, leaf water movement suggested to be influenced by mesophyll architecture which contributes to water flux in the mesophyll and water evaporation at the cell wall surface (Tomás, 2012; Flexas et al., 2013). On the other hand, Martorell et al. (2015) found in two *V. vinifera* cultivars (Tempranillo and Grenache) that leaf vulnerability at 50 % and 80% loss of K_{leaf} (P50 and P80) as well as the maximum K_{leaf} decreased seasonally by more than 20%. However, K_{leaf} plasticity along leaf lifespan was different between the two cvs. Only the cv Tempranillo showed an increase of K_{leaf} at −2 MPa in the months of June and July, while Q4 Jones and Grant (2015) osmotic potential at full turgor was lower in Tempranillo than in Grenache. They showed as well that leaf resistance to hydraulic dysfunction is cultivar dependent and also a seasonal plastic trait that can be mediated by osmotic adjustment (Martorell, 2014; Martorell et al., 2015).

Regarding root traits, root hydraulics and morphology are two determinant traits influencing grapevine water relations. Higher hydraulic conductivity correlates well with higher drought tolerance of grapevine rootstocks (Schultz, 2003; Zufferey et al., 2011; Tramontini et al., 2013; Serra et al., 2014). Vigorous rootstocks showed larger hydraulic conductivity of fine roots, which is partly attributed to aquaporin expression and activity (Gambetta et al., 2013).

Root system morphology (root distribution and depth) depends on the interaction between the rootstock genotype and the surrounding environment (soil texture, bulk density and salinity, water and nitrogen availability, planting density and climatic conditions) (Koundouras, 2008). Grapevine roots have larger xylem vessels than those of stems, which causes them to be more prone to xylem cavitation (Lovisolo et al., 2008). It has been suggested that the adjusting capacity of roots to supply water relative to shoot transpiration demand is a major means for woody perennial plants to tolerate drought and it is often expressed as changes in leaf to root area ratio (Alsina et al., 2011). Different combinations of xylem vulnerability to cavitation with stomatal kinetics results in multiple degrees of *isohydry/anisohydry* in various plant species/cultivars (Tombesi et al., 2014). These authors suggest that *V. vinifera* near-isohydric and anisohydric genotypes differ in terms of xylem vulnerability to cavitation as well as in terms of petiole hydraulic conductivity, and that coordination of these traits results in different stomatal responses under water stress conditions. More recent findings on roots point out to the contribution of root-associated bacterial microbiome to grapevine adaptation to water stress by via increased root biomass and improved water absorption capacity (Rolli et al., 2014). This alternative way to promote drought resistance in grapevine demands more research to better comprehend the effects of soil microbiology on grapevine performance against stress.

2.3. Hormones and metabolites

Contrary to hydraulic signals, the role of biochemical signals in stomatal regulation is well described (Schroeder et al., 2001; Chaves et al., 2003; Pantin et al., 2013; Carvalho et al., 2015). Chemical signals with origin in roots are particularly important for grapevine adaptation to water especially at the early stages of stress (Schachtman and Goodger, 2008; Dodd, 2009; Tsegay et al., 2014; Tardieu et al., 2015). Cultivar-specific differences in stomatal control in response to drought have been attributed to differences in abscisic acid signaling and perception machinery (Soar et al., 2006; Perrone et al., 2012) and/or as a consequence of different patterns of aquaporins expression and/or activation (Vandeleur et al., 2009; Perrone et al., 2012; Pou et al., 2013).

More recent studies point out the relevance of certain metabolites (e.g. polyols) in the adaptation to drought in grapevine. The impact of polyols on grape berry composition and plant response to water deficit was described for the variety Tempranillo grown in greenhouse and field conditions (Conde et al., 2015). Both sorbitol and mannitol limited size reduction of berry cells under drought (Conde et al., 2015). The authors suggested that grapevine cultivars which accumulate polyols as a tolerance mechanism to drought stress might have adaptive advantages under unfavourable growing conditions as they would require less water along the season to sustain yield and berry quality (Conde et al., 2015). It was also suggested that synthesis, transport and accumulation of sugar alcohols may work as bioindicators of plant health and acclimation and can be used as potential biomarkers in crop breeding (Merchant and Richter, 2011; Conde et al., 2015).

2.4. Stress-recovery responses

An important component of the studies on plant stress responses is the analysis and comprehension of the efficacy and related underlying mechanisms involved in recovery from water stress following rehydration (Flexas et al., 2009; Bondada and Shutthanandan, 2012; Pou et al., 2012; Sapeta et al., 2013). Fast and efficient recovery from water stress is a key characteristic of the species/genotype adaptation to changing soil and air meteorological conditions (Perrone et al., 2012; Torrez Ruiz et al., 2014). This is highly relevant to understand grapevine capacity to overcome/recover from water stress after a rainfall event and when subjected to deficit irrigation in which successive cycles of water stress/recovery are imposed to vines (Pou et al., 2008; Lopes et al., 2014). Plant's carbon balance during water stress and recovery cycles depends on the velocity and degree of photosynthetic recovery as well as on the degree and velocity of the photosynthetic decline during water depletion (Flexas et al., 2006). Plants subjected to severe water stress recover only 40–60% of their maximum photosynthesis rate during the first day after re-watering and maximum photosynthesis rates are often not recovered (Gallé and Feller, 2007; Pou et al., 2008). The severity of the previous water stress was shown to have a major influence on the velocity and extent of photosynthesis recovery in different species (Miyashita et al., 2005) including grapevine (Gómez-del-Campo et al., 2007; Pou et al., 2008; Flexas et al., 2009). Recovery of photosynthetic capacity after drought depends on restored xylem function although few data on grapevine exist to elucidate this type of coordination (Martorell, 2014). Knipfer et al. (2014) showed that responses to drought and recovery capacity involved the maintenance/recovery of xylem transport capacity in coordination with root pressure as well as leaf gas exchange responses. More research at molecular level on water stress recovery in grapevine is needed to explain grapevines' genetical variability on hydraulic and leaf gas exchange traits in response to drought stress (Perrone et al., 2012; Coupel-Ledru et al., 2014).

3. Agronomic strategies in modern viticulture in dry areas

3.1. Water saving strategies

Irrigation is one of the most effective tools to manipulate berry yield and quality in dry areas (Costa et al., 2007; Romero et al., 2010; Forbes et al., 2009; Flexas et al., 2009, 2010). Deficit irrigation (DI) based on the application of water below the water losses by the crop, has been largely pointed out as a reliable technique to improve water savings and productivity in grapevine (Santos et al., 2003; Chaves et al., 2007; Medrano et al., 2003, 2015). The strategy involves soil drying and re-wetting cycles with varying frequencies and intensities during the growing cycle and is deliberately used to enhance crop WUE (Dodd et al., 2009). A specific case of deficit irrigation is partial root drying (PRD). Typically, in the PRD strategy one part of the root zone is irrigated at a time, with the wet and dry parts of the root system being periodically alternated to increase ABA signalling transiently and/or prevent excessive soil drying diminishing the transport of chemical signals to the shoot (Kang and Zhang, 2004; Dodd, 2009). PRD resulted in higher WUE, water savings and improved berry quality in grapevine (Santos et al., 2003; Souza et al., 2005). However, the PRD strategy involves more complex management and higher installation costs (e.g. double amount of irrigation tubes), making it less adequate for commercial use. Besides literature presents contrasting results for PRD, as function of the soil characteristics and genotype (Santos et al., 2003; Romero et al., 2012) Table 1.

Although the general effects of deficit irrigation are well described in literature (Chaves et al., 2007; Dodd, 2009; Flexas et al., 2010), it is still not fully covered how different genotypes perform in response to mild to severe water stress in combination with particular soil and atmospheric conditions. Genotypic heterogeneity of *V. vinifera* species forces growers and farm managers to look more carefully to the water use traits of the cultivars growing in their farms in order to tune water irrigation volumes in the different plots of the vineyard. In addition, the interaction between genotype and the rootstock and their compatibility is a highly relevant issue with major consequences for plant hydraulics and water transport, and thus, for stress resistance (Gökbayrak et al., 2007; Serra et al., 2014).

The water reuse option can be considered as a cost-effective solution for Mediterranean agriculture. Water reuse reduces the need to develop new water resources and provides an adaptive solution to climate change and it has the advantage of valorising the social and environmental value of water by enhancing water resources availability and minimising wastewater outflow with additional environmental benefits (Lazarova et al., 2001; MED-EUWI, 2007; Raso, 2013). In many of the arid and semi-arid regions of the Mediterranean, recycled wastewater is being used as an affordable alternative resource for agricultural, industrial and urban non-potable purposes (Lazarova et al., 2001; Angelakis and Gikas, 2014). In countries like Australia and Israel, the use of recycled water is proving to be a viable alternate source of water for irrigation of crops (Angelakis and Gikas, 2014). The potential benefit can even be larger in case the wastewater treatment facilities are also expanded and optimized. Currently in Spain, 408 hm^3/year are reused (13% of total available water) of which 79% are for agricultural irrigation (320 hm^3/year). Waste water use might be employed to mitigate drought stress, but the short and mid-term detrimental effects of salt stress should be quantified. Non-conventional waters are source of nutrients, particularly nitrogen and phosphorous which may potentially modify berry composition and plant's WUE (Bell and Henschke, 2005). Implementing effluent reuse projects results in extra applied loads of nutrients that must be carefully accounted for, due to the potential harmful effects on environment and/or plant performance (Paranychianakis et al., 2006). Together with environmental risks, the risks for human health must be also be studied and demand strict guidance and quality control (MED-EUWI, 2007). The use of recycled water needs to be better studied in viticulture (SARDI, 2009).

3.2. Canopy and soil management

It has been shown that warming conditions results in an advance of phenological stages with flowering and *veraison* occurring earlier with respect to the baseline and in a shorter inter-phase time (Palliotti et al., 2014). There are also situations in which occurs a

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Table 1
Non-exhaustive list of water saving, best water management practices and water conservation strategies to be implemented at different scales, the vineyard, the winery and the region.

Water saving & conservation strategies	Physical site		
	Vineyard	Winery	Region
Install flow meters on wells or at the pump or down individual rows to estimate water use (in the vineyard and winery); Record data regularly, set a standard value and search for discrepancies	X	X	X
Guarantee maintenance of the irrigation system (filters, flow meters, gutters, lines) by periodic checking pipe connections and taps for leaks	X		X
Deficit irrigation, use well adapted variety/rootstock, proper soil characterization (profile, water capacity, fertility)	X		X
Precise crop/soil monitoring (measure periodically soil and plant water status (e.g. leaf water potential), measure vineyard's evapotranspiration)	X		
Implement "Good Environmental Management Practices" for water, biocide and fertilizer management, soil management and machinery and vehicle management	X		X
Use pond process water for vineyard and/or landscaping irrigation; Use drought tolerant species for landscape purposes	X		X
Reduce water use in the winery cellar by using water saving alternatives (e.g. install an ozone system for winery equipment cleaning/sanitation), monitor water use in washing/soaking of barrels, install specific flow meter(s) to assess water use in cleaning operations along the vinification procedures		X	
Improve waste management and treatment by adapting and implementing more cost effective treatment technologies for winery effluents and solid residues		X	X
Promote and guarantee staff training (crop management, irrigation water use, winery cleaning, environmental risk assessment and general management)	X	X	X
Optimize technical assistance and support to wine producers to meet environmental regulations, improve their image near consumers and their sales	X	X	X
Water use benchmarking to set reference values. Develop "water performance" indicators for both the vineyard and winery, Set targets and implement auditing, and reporting	X	X	X
Quantify market benefits by adopting environmental management systems and by promoting environmental credentials to guarantee a good environmental management	X	X	X

Sources: (Skewes, 1998; COTR-ATEVA, 2009; CWSA, 2011, 2012; CRCV, 2015; Retallack, 2012, 2013; SUSTAVINO, 2012; WATERWIKI, 2015; Radke et al., 2015).

decoupling between anthocyanins and sugars accumulation. Grape ripening is generally accelerated as per increment of sugar accumulation into the berries which in turn can lead to higher alcohol content in the wine if harvest is not anticipated. Moreover, elevated temperatures are also known to induce negative effects on wine colour as a consequence of thermal decoupling of berry anthocyanins and sugars accumulation (Sadras and Moran 2012). There is an increasing number of domestic and foreign consumers preferring wines with moderate alcohol content.

For wine making, significant benefits were described from comprehensive approaches to control shoot vigour through the use of different methods of winter pruning and canopy management such as shoot trimming or thinning (Smart, 1985). Shoot thinning is one of the most widely applied practices in vigorous vineyards to reduce canopy density, optimize sunlight interception, photosynthetic capacity, and fruit microclimate and ultimately improve fruit yield and wine quality. Soil management strategies (tillage vs non-tillage) can also induce changes in the canopy microclimate via indirect effects of water and nutrients competition on vine vegetative growth (Monteiro and Lopes, 2007). The aims of soil surface management in a typical Mediterranean vineyard are multiple encompassing improved weed management and soil conservation, the reduction of soil resource availability to control vine vigour and thus influencing berry composition and in wine quality (Monteiro and Lopes, 2007; Lopes et al., 2011; Guerra and Steenwerth, 2012). In Mediterranean conditions the most widely used soil management practices are soil cultivation in the inter-row combined with herbicides in the row or other control strategies more recommended in biological/organic vineyards. Living green ground covers (grass cover, sown or natural) are also used but not so often because of the concern of excessive water and nutrients competition between the swards and vines (Prichard, 1998; Celette et al., 2008; Lopes et al., 2011, 2015). Indeed when using cover crops in semi-arid areas, favourable effects can be counterbalanced by excessive water competition (Medrano et al., 2014; Lopes et al., 2011) especially if winter and spring periods are dry and/or irrigation water is scarce.

The dual strategies involving soil tillage and the use of cover crops is still matter of debate and solutions are greatly linked to the concept of "terroir" (Pou et al., 2011; Lopes et al., 2014; Medrano et al., 2014). The effects of cover crops on grapevine vigour, yield and berry composition depend on the "terroir", being either (i) beneficial to control vegetative growth and increase berry colour in the case of vigorous genotypes/varieties combined with high spring rainfall or (ii) detrimental, in case of low vigour genotypes/varieties and/or of semi-arid and/or extreme environments because they can result in an excessive reduction in vigour and yield (Pou et al., 2011). Since the impact of the competition between swards and vines changes along the season (Lopes et al., 2008), extended trials are needed (Peterson et al., 2012) to assess the consequences of such type of management approach on vine longevity and in a specific 'terroir'.

3.3. Selection of rootstocks and varieties resistant to drought and heat

Among the possible adaptive agronomic measures to use in modern viticulture under the ongoing climate change conditions is the selection and cultivation of the best adapted rootstocks and varieties based on differences in temperature requirements for their cultivation (Jones et al., 2005) and WUE characteristics (Costa et al., 2012; Chaves et al., 2010; Tomás et al., 2014a). The right combination of variety/rootstock for a certain environment can determine drought and heat tolerance. Rootstocks influence vigour and drought tolerance via differences in root growth, root hydraulic capacity and also stomatal behaviour (Tandonnet et al., 2010; Cookson and Ollat, 2013; Pavloušek, 2013; Serra et al., 2014). Different rootstocks show varying capacities to extract soil water and transfer it to the scion (Soar et al., 2006), which can be attributed to different efficiency on water transport due to variable xylem vessels anatomy (De Herralde et al., 2006). Different rootstock genotypes show also different root traits (e.g. density and depth); deep and bushy root system permit larger uptake of water and nutrient and a more adequate response to drought and heat stress (Paranychianakis et al., 2006; Koundouras et al., 2008; Pavloušek, 2013; Tramontini et al., 2013). On the other hand, roots have large carbon requirements (e.g. high respiration represents 70–80% of the total carbon losses (Serra et al., 2014)). Therefore, genotypes with more efficient root systems would be a comparative advantage for dry regions and thinner soils as they would enable a more effective exploitation of soil resources with smaller carbon losses.

3.4. Precise plant monitoring and phenotyping

Modern Precision Viticulture involves the use of technologies in which imaging, artificial vision and robotization/automation have a central role and can help to decrease costs and improve input use efficiency such as of water, fertilizers, biocides and energy.

Precision Viticulture is based on technologies that are able to detect spatial heterogeneity of vineyards either due to intrinsic factors (soil and crop management) and/or external variables (climate) and that ultimately will determine inter-annual and intra-vineyard variability with regards to yield and quality output (Mazzeto et al., 2010; Matese et al., 2015; Jones and Grant, 2015). Manual ground-based and aerial manned and unmanned remote sensing measurements are being progressively implemented in modern viticulture not only in research but also in commercial vineyards to monitor plant stress and or to assess canopy and/or berry traits (Costa et al., 2010; Grant et al., 2007; Grant, 2012; Fuentes et al., 2014; Fernández et al., 2013; Jones and Grant, 2015). These new approaches combine the use of different types of detectors and spectral wavelengths ranging from visible (red, green, blue) (RGB) and infrared thermal imaging to multispectral and tomography measurements (Leionen et al., 2006; Diago et al., 2012; Fuentes et al., 2012; Costa et al., 2013; Jones and Grant, 2015; Rustioni et al., 2014). Robots and unmanned Aerial Vehicles (UAVs) have been recently applied in precision viticulture (Baluja et al., 2012; Zarco-Tejada et al., 2009, 2012; Gago et al., 2015). UAVs offer advantages relatively to ground based measurements. UAVs have high flexibility of use, low operational costs and a very high spatial resolution, that can be down to 1 cm (Matese et al., 2015; Gago et al., 2015). However, the legislation regulating their use in certain EU countries demands still clarification for a broader use in agriculture (Costa et al., 2013). Satellite imaging has also been used in grapevine studies namely to assess water stress (Consoli and Barbagallo, 2012) and intra-variability in vigour and leaf expansion (Matese et al., 2015; Jones and Grant, 2015)

Soil monitoring is another relevant aspect of remote sensing. Assessment of soil water in field conditions must be accurate especially over large and heterogeneous surfaces. Electrical Resistivity Tomography meets these requirements for applications in plant sciences, agriculture and ecology (Brillante et al., 2014). Also the combined use of aerial and ground based thermal imaging permits to monitor soil water in vineyards (Soliman et al., 2013). These authors found that spatial patterns of soil moisture correlated better with thermal inertia data than with measured surface temperature and suggested to use it as a potential indicator for vineyard irrigation management. Optimizing the use of thermal and vegetation indexes as means to gather more robust information on crop water stress is another important component of crop monitoring based on thermography.

Regarding plant phenotyping, since grapevine is a perennial field crop, acquisition of phenotypic data is almost restricted to the field and is usually carried out by visual estimation. This is time consuming and can be affected by subjectivity. Consequently, fully and/or partially automated phenotyping is needed to increase the number of samples monitored to manage grapevine repositories, to enable genetic research of novel phenotypic characteristics and ultimately to increase efficiency in grapevine phenotypying and breeding (Kicherer et al., 2015). Moreover, the available high-throughput phenotyping platforms can contribute to improve grapevine phenotyping and breeding (Kicherer et al., 2015). Phenotyping canopy traits can be simpler to perform by imaging than fruits and roots. Recent results in grapevine showed that visible RGB images permit to assess bunch compactness (Cubero et al., 2015) and a high-throughput image interpretation tool to acquire the number, diameter and volume of grapevine berries (Berry Analysis Tool—BAT) has been recently developed (Kicherer et al., 2013). Finally, cheaper and more user friendly technologies for crop monitoring and phenotyping are on demand. As an example, Fuentes et al. (2014) have recently proposed an inexpensive but robust automated computational method to obtain leaf area index and canopy vigour parameters from grapevines based on RGB imaging and video analysis with MATLAB.

4. Sustainable water use

4.1. Sustainability standards and water use indicators

The wine industry, just like any other intensive agribusiness activity or sector's of industry has an environmental impact that must be obligatorily taken into account for consideration. Although wine production is one of the most innovative and competitive industries at global scale, the environmental issues remain overall poorly perceived (Barber et al., 2009; Marshall et al., 2005; Christ and Burritt, 2013). Therefore a more objective quantification of its environmental impact is crucial particularly in terms of water use. Water performance metrics involves a precise quantification of water inputs and outputs in the vineyard and winery making it easier to assess their environmental and economical performance (CWSA, 2011). Performance metrics also contributes to predict future water needs and expenses which is particularly relevant under unfavourable scenarios (stressful environments, water scarcity) and stricter environmental rules (CWSA, 2011). Unfortunately, numerous indexes available to classify "sustainability" of the wine sector shows that there are differences among countries which makes it more difficult to classify companies because of the differences in index composition and in the trait of sustainability under observation (Santini et al., 2013). In California, the use of metrics permitted the use of natural resources (water, energy) and helped to optimize vineyard operations, reduce costs and increase sustainability (CWSA, 2011). In New Zealand, vineyards and wineries can report water use per vineyard and per winery annually to the Sustainable Winegrowing New Zealand and this information will be used to establish benchmarks for members (www.nzwine.com). Australia in turn has been promoting for a long time, water use benchmarking of vineyards (Skewes, 1998; Walker and Boland 2004) and in Portugal, the same approach was was carried out for Alentejo's wine region (COTR-ATEVA, 2009). Skewes (1998)

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suggests a set of potential indicators for water use such as: (1) Yield (ton/ha); (2) Crop WUE (ton/water use); (3) Return per water applied; (4) Cost of water per tonne of fruit; (5) Irrigation efficiency; (6) Yield per volume of drainage (Ton/m^3 of water) or (7) Cost of drainage per tonne of fruit (Euros/ton). In addition, the relationship of these water use indicators with major berry/wine quality attributes (e.g. sugar content, colour, flavour and aroma components) should be also considered in future audits. Benchmarking approaches would help to improve efficiency by setting a standard and a reference. However, we may have also to consider that some small farms and businesses are not willing to present their own results nor being evaluated by their counterparts. The use of more objective parameters and performance metrics are also needed for South European Mediterranean regions such as in Portugal and Spain.

4.2. Water foot print (WFP) and Life cycle analysis (LCA)

The strong and growing trend towards industry certification in terms of environmental sustainability is being translated into concepts such as ecological footprint (Hoekstra et al., 2011; Ene et al., 2013; Lamastra et al., 2014). The concept of water footprint (WFP) emerged as a basic, theoretical, consumption-based indicator of water use and looks at both direct and indirect water use by a consumer or producer (Hoekstra et al., 2011). It is calculated by the volume of fresh water used to produce the product, measured over the various steps of the production chain (Hoekstra et al., 2011). For food crops, the WFP concept includes all the fresh water consumed per unit of product (e.g. per litre of wine), namely to grow the crop, the water used in post-harvest processing and also the polluted water produced (volume of freshwater required to assimilate the pollutants load). The WFP is being used to indicate the impacts of water use by production systems and there have been an increasing number of governments/companies recognising that reducing WFP is part of the country/corporation environmental strategy (Hoekstra and Mekonen, 2012; Herath et al., 2013).

An important recent development is the fact that the International Organization for Standardization (ISO) developed the International Standard ISO 14046, “Environmental management—Water footprint—Principles, requirements and guidelines”, which aims at providing decision makers in industry, government and non-governmental organizations with the means to estimate the potential impact of water use and pollution, based on a lifecycle assessment (http://www.iso.org/iso/iso14046_briefing_note.pdf). This has enlarged the set of indicators related to environment sustainability and water use and protection that ISO makes available for the industry.

However, there are some authors arguing on the effectiveness of WFP as neither WFP is as accurate as a hydrological based approach nor a helpful indicator of water use and water management in agriculture (Perry, 2014). Therefore, the classical WFP requires more refinement for food groups, especially in the case of grapes and wine. In fact WFP should incorporate large regional/temporal variation for agricultural products due to the variable environmental context (Hoekstra et al., 2011; Maes et al., 2009; Berger and Finkbeiner, 2011; Vanham and Bidoglio, 2013), different agronomic strategies (e.g. irrigation vs non irrigated) or different growth and water use performance of genotypes which generates variation in evapotranspiration. This seems not to be sufficiently accounted in the classical calculations of WFP. Moreover, generalized values for WFP for a certain commodity can hide differences between regions and may mislead consumers and authorities (Maes et al., 2009; Perry, 2014). In addition, the classic WFP estimation has also limitations in the assessment of relevant water issues such as water quality and water pollution.

Together with the WFP, the Life Cycle Assessment (LCA) methodology provides a possible framework to evaluate environmental impacts of products and production systems across their entire lifespan and can be applied to durable, disposable or edible goods including food products (Notarnicola et al., 2012; Gazulla et al., 2010; Arzoumanidis et al., 2013, 2014; Torrellas et al., 2013). The LCA is a standardized method which is in accordance to the ISO rules (ISO 14040:2006 and ISO14044:2006) (ISO, 2006; Barjoveanu et al., 2010; Finnveden et al., 2009; Teodosiu et al., 2012).

There are still few literature studies on the environmental effects of wine production on a complete lifecycle perspective (Gazulla et al., 2010; Benedetto 2013). These studies have shown that the major bottlenecks and environmental impacts in wine production refer to the viticulture phase and also to glass production for bottles. In fact, the largest percentage of water use in the wine supply chain relates to the cultivation phase whereas a minor percentage resides in the vinification and production of packaging materials (Ene et al., 2013). To guarantee a wider use of LCA information, there is a need to simplify LCA methodology and determination (Torrellas et al., 2013). This is especially true if we consider the characteristics of the wine sector in the Mediterranean characterised by a large number of small- and medium-sized Enterprises (SMEs) with limited knowledge or resources to implement the conventional full LCAs (Arzoumanidis et al., 2014). A simplified LCA tool is now available online, the eVerdEE tool (http://www.ecosmes.net/everdee/login2 (accessed on 10 July 2014)) that allows its users to directly fill it in and obtain results with regard to the environmental performance of a product. This tool can be accessed for free, after registration (Arzoumanidis et al., 2014).

4.3. Legislation and statistics for sustainable water use

Legislation and statistics on water use and management is essential to guarantee the optimal use of scarce resources. Five major categories of tools can help to implement and guarantee a proper management of water at regional and national levels: regulatory, enforcement, economic, participative and integrated (Medellín-Azuara et al., 2013) (See Table 2). In the case of EU, the main policy objectives in relation to water use and water stress were set out in the 6th Environment Action Programme (EAP) (1600/2002/EC) and the Water Framework Directive (WFD,2000/60/EC) whose major aim is to ensure the sustainable use of water resources. The more recent policy document is the ‘Blueprint to safeguard Europe’s water resources’ (COM/2012/0673) which aims at ensuring that good quality water of sufficient quantity, is available for all legitimate uses (EUROSTAT, 2015). The “Blueprint” is a new strategy to reinforce water management in the EU and is closely related to the Europe 2020 strategy, in particular, to the roadmap for resource efficiency (EU Commission, 2014a,b; EUROSTAT, 2015). Concerning this topic, the EU Commission had already issued in 2007 a Communication on Water Scarcity and Droughts, establishing five pillars: (1) put right price tag on water, (2) promote more efficient water related technologies and practices, (3) improve drought risk management, (4) enhancing a water-saving culture and (5) improve knowledge and statistical data collection (EEA, 2012a,b). However, EU’s architecture can be problematic for down-scaling water policies to national, regional and local levels, resulting in not common objectives among different EU members (Villarejo and Lopez, 2014). In Portugal, an implementation program for legislation on water issues has been implemented (“Plano Português para Uso Eficiente de Água”) and Spain, in turn, put in place the so called “Plan Nacional del Agua”.

Accurate statistics and estimation of water use and irrigation demands is a key requirement for precise water management (Maton et al., 2005) and a large scale overview on European water use can contribute to developing more correct water management

Table 2
Indicative list of resources and policy tools to govern water management and water conservation.

Resources and measures	Description of the tools
Water statistics	• Water statistics are crucial to report obligations to international organizations (UNSD/UNEP, Eurostat/OECD) and to support EU and national management of environmental and socio–economic conditions for a more sustainable development • Robust water statistics will support a more correct use and implementation of different measures (regulatory, enforcement, economic, participative)
Regulatory measures	• Contains the instruments to conserve overexploited basins/aquifers by implementing prohibitions, reserves and regulations
Enforcement measures	• Involves enforcement regulations to control and manage the use of water and water discharge • Implementation based on field inspections, quality monitoring, auditing, sanctions for misconduct
Economic measures	• Use economic instruments (incentives) to implement novel water policies and regulations following the principle of "water user pays" and "polluter pays" • Use incentives that may include lower taxes for growers/wineries showing higher water use efficiency and more sustainable practices. The use of incentives to promote efficiency should be considered by both regional and central governments • Water pricing/charges applied on a volumetric basis
Participative and integrative measures	• It is a policy tool to promote community participation in planning, policy development and water management. It involves participation of water user associations, technical committees for water resources, representatives of different sectors (e.g. tourism, agribusiness, national and regional water management authorities). • Involves awareness-raising by stakeholders and dissemination of information/statistics concerning water.

Sources: (EEA, 2012a,b; EU Commission, 2014a,b; D'Amore, 2005; Medellin-Azuara et al., 2013; Radke et al., 2015).

policies and strategies. However, there is still a significant lack of water related statistical information for policy decision on aspects such as aquifer recharge, water abstraction by farmers, irrigation pollution emissions from either surface or subsurface water, soils (Albiac et al., 2005; EEA, 2012a,b; Ferreira et al., 2015). In fact, Portugal lacks up-to-date statistics related to water and there is large discontinuity of data related to water uses and water masses (Ferreira et al., 2015). Unfortunately, the problem of scarcity, non homogeneous and disaggregated statistical data seems to be experienced by other Southern European countries as well (Albiac et al., 2005; EEA 2012a,b).

5. Consumer perspectives and marketing

Consumer awareness of sustainable winegrowing and winemaking remains low and the concepts such as "sustainable product" or "sustainable processes" are confounded with vague terms e.g. "organic" and "green" (Zucca et al., 2009). However, the perception on the assessment of environmental and economic sustainability of wine's supply chain by stakeholders is increasing and becoming a concern for growers, entrepreneurs, consumers and public decision makers (Point et al., 2012; Strano et al., 2013; Dawson et al., 2011; Fountain and Tompkins, 2011; Pullman et al., 2010; Radke et al., 2015). The wine industry should develop appropriate marketing strategies to help consumers to identify and distinguish between sustainable and non sustainable products (Zuca et al., 2009) and avoid any type of marketing practices that may mislead consumers about firm environmental performance or benefits of a certain product or service (so called "greenwashing") (Delmas and Cuerel Burbano, 2011). This has the negative effect on consumers and investors' confidence in environmentally friendly firms and products (Delmas and Cuerel Burbano, 2011) and jeopardizes efforts of stakeholders to build up a true and effective sustainability concept. In a recent transnational study, wineries have also complained about the lack of information existing among relevant organizations, producers and consumers in terms of environmental sustainability (Szolnoki, 2013). This requires increased cooperation between organizations/associations to optimize the flow of information in the wine supply chain (Christ and Burritt, 2013; Broome and Warner 2008; Santini et al., 2013).

6. Final considerations

Future scenarios for the Mediterranean viticulture encompasses approaches at different levels (from plant physiology to consumer behaviour) to guarantee a more economically and environmentally sustainable wine production. The sustainable use of water is of outmost importance and must be guaranteed at the vineyard, winery and regional levels. Therefore, future strategies to optimize the environmental performance of the wine sector in the Mediterranean must be focused on water. This starts in the breeding for improved plant adaptation to heat and drought stress and ends in strategies to save water in the vinery and winery. Robust water use statistics at both EU and national levels are needed. Also the correct use of indicators (WFP, LCA, ISO norms) coupled to effective water policies will help make the Mediterranean wine industry more efficient in terms of water use minimizing its environmental impact.

Improved crop performance under more stressful conditions of water by controlling grapevine water relations and canopy temperature should take place in parallel with optimized deficit irrigation and water reuse. Soil maintenance influencing soil and plant water relations as well as soil fertility and temperature will have impact on plant performance and berry quality. Nowadays, a large set of technologies is available for ground and aerial sensing but novel technologies must be better integrated and properly validated for different genotypes and for different strategies of plant and soil management. Low cost but effective remote sensing technologies would help to generalise their use by an increasing number of small companies and growers.

Water statistics and improved performance metrics at the vineyard and winery are required to optimize water use along the supply chain. Proper audit programs to water use should be promoted by authorities, association or organizations related to wine supply chain. Consumer perception on wine industry impact on the environment tends to increase and requires novel approaches to operate in the wine supply chain. New concepts have been

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emerging in the modern viticulture namely the ecological footprint (water, carbon, social) and "vinecology", which emphasises the need to integrate ecological and viticultural practices to guarantee nature conservation, landscape protection and diversity (Viers et al., 2013). In addition, wine tourism is now an important complement of wine production worldwide (Barber et al., 2009, 2010) including Portugal and Spain (Radke et al., 2015; Gómez and Molina, 2011). Landscape scenery and the environmental attractiveness have become major components of the wine tourism and must be also protected (Bruwer and Alant, 2009; Leddy, 2013; Dawson et al., 2011; Fountain and Tompkins, 2011). Therefore, tourism can be an extra trigger for farme and winery managers to implement best management practices in the vineyard and winery, and ultimately contribute to minimize the environmental impact of the wine industry.

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