COVER CROPS COMPETITION FOR WATER IN VINEYARDS: CASE STUDIES IN MEDITERRANEAN TERROIRS

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Abstract

Vineyard cover cropping is a cultural practice widely used in many of the world's winegrowing regions being one of the most recommended practices to face climate changes and to promote vineyard environmental sustainability. The benefits of using cover crops are many ranging from environmental protection (e.g. control of soil erosion, enhancement of soil structure and biodiversity, sequestering carbon) to vineyard management, including control of vigor and improvement of berry composition. Despite those potential benefits, the adoption of cover crops in Mediterranean non-irrigated vineyards has been limited by the concern of excessive water competition between cover crops and vines. However the level of this competition should be better understood as in warm and dry terroirs, like the case of Mediterranean winegrowing regions, water competition by the cover crops is effective mainly during spring. During summer, the almost absence or rainfall induces the dry out of the sward vegetation which residues became dead mulch that can even reduce soil evaporation. Furthermore, some research has also demonstrated that, after some years of competition with swards, the vines were able to develop deeper roots, therefore increasing the capacity for water extraction from deeper soil layers.

In order to further elucidate the above mentioned topics, in this paper data on water use and grapevine performance obtained in three floor management experiments (soil tillage vs. inter-row swards), carried out in three different winegrowing regions of the Mediterranean Portugal (covering rainfed and irrigated vineyards), will be presented. Discussion will be focus on water competition by the swards and corresponding effects on grapevine vigor, yield and berry composition. The effect of terroir on grapevine responses will be also underlined. From the data presented it can be concluded that cover crops is a vineyard management practice that can have a positive influence on water use efficiency, either by preventing vine excessive vigor when water is fully available during spring or by maximizing the volume of soil explored by vine roots through the enhancement of the exploitation of soil water reserves into deeper layers. However, in the case of low vigor vineyards located in dry terroirs, the degree of water competition between cover crops and vine must be carefully monitored and managed (e.g. by increasing mowing frequency, reducing the sward strip and/or choosing less competitive species) and adjustments in conventional irrigation management are necessary in order to avoid detrimental effects on grapevine yield and longevity.

Key words: Grapevine, resident vegetation, soil management, soil tillage, water use.

1 INTRODUCTION

Vineyard cover cropping is a sustainable soil management practice extensively used in many of the world's viticultural areas being one recommended practice to promote environmental sustainability and to face climate changes in vineyards (Schultz & Stoll 2010). The benefits of using cover crops range from environmental protection to vineyard management, including control of vigor, yield and grape health and composition (Guerra and Steenwerth 2012). Despite those potential benefits, the adoption of cover crops in areas with Mediterranean-type climate has been limited by the concern of excessive water competition between the cover crops and vines.

Cover crops compete with the vine for water resources and can have an important contribution to the vineyard evapotranspiration. In a furrow-irrigated Australian vineyard Yunusa et al. (1997), reported transpiration rates higher than 3.0 mm/day for a mixture of *Trifolium repens* L. and *Lolium perenne* L.. At Germany Weiss et al. (2002), using direct measurements on a continuous grass cover sedum album mixture, found transpiration rates per month between 29.3 mm for April and a maximum of 51mm in June and an estimated April-September cumulative ET of 251.1mm. In another experiment conducted in Germany, Lopes et al. (2004) estimated the evapotranspiration of a vineyard cover crop between 4.45 and 0.71 mm/day, depending on the species. In Italy, in a chamber experiment, Centinari et al. (2009) reported consumption rates of a 100% coverage permanent sward of *Festuca arundinacea* Schreb. between 2.9 and 4.3 mm/day during August. McDonald et al. (2010) estimated the evapotranspiration from cover crops in Australian vineyards at over 200 mm per season. In a study conducted in the state of

New York, USA, Centinari et al. (2011) using mini-lysimeters, reported cover crop evapotranspiration rates ranging from 0.6 to 2.6 mm/day. Uliarte et al. (2013), using whole-canopy chambers under field conditions in Germany, found a large variability in the water consumption for several C3 and C4 cover crop species (ranging from 0.92 to more than 3.0 mm/day).

In Mediterranean non-irrigated viticultural areas cover crops competition for water might induce the development of vine water stress (Prichard 1998, Afonso et al. 2003, Lopes et al. 2011, Celette and Gary 2013). However the interactions between cover crop and vines regarding water use and competition are still poorly understood and the published results are very variable and sometimes contradictory. For example, in Germany Böll (1967) estimated additional water consumption in the spring (May-June) between 0.31 and 1.2 mm/day for closed stands of different cover crop species. In a field experiment performed in Portugal, in a coastal area Monteiro and Lopes (2007) estimated an additional water use between budburst and harvest ranging from 4 to 9% in the resident vegetation and sown cover crops respectively, as compared to a tillage treatment. In the study of Centinari et al. (2011) the cover crops induced an additional evapotranspiration ranging from 0.6 to 2.6 mm/day. In another study in southern Portugal, Lopes et al. (2011) found a 39% additional water use in Spring (end of April -end of May) from a mid-row resident vegetation as compared to soil tillage however no significant differences were detected for the entire season.

Cover crops evapotranspiration depends also on other factors such as vineyard row orientation, canopy height and inter-row space, the cover crop species and percent of soil coverage, height and architecture of the cover crops vegetation and on the cover crops management, mainly the frequency and mowing dates (Prichard, 1998, Lopes et al. 2004, McDonald et al. 2010; Uliarte et al. 2013). For example Lopes et al. (2004) found that, throughout the day, lower cover crops transpiration rates corresponds to the times at which the rows cast shadows onto the inter-row prevented the direct sunlight to reach the ground.

Besides all the above mentioned factors the amount and distribution of the rainfall during the growing cycle will determine also the contribution of the cover crops for seasonal evapotranspiration. In Mediterranean-type climates the more intense water uptake by cover crops is mainly during spring (Monteiro and Lopes, 2007; Cellete et al. 2008, Lopes et al, 2011, Cellete and Gary 2013) and, usually, the cover crops plants stop growing or even dry out during the summer, thus creating a dead mulch that can reduce evaporative losses of soil water (Skrotch and Shribbs, 1986; Prichard, 1998).

The plasticity of the grapevine root system and its high sensitivity to soil water content may also contribute to limit the competition for water between the cover crops and the vine. Indeed, after some seasons of competition it was shown that the number of vine roots in the inter-row tends to be reduced but is counter-balanced by the development of deeper roots in the row, increasing the capacity for water extraction in deeper soil layers (Morlat and Jacquet, 2003; Cellete et al., 2005; 2008). This behavior was also inferred by tracking changes in volumetric soil water content in the three Portuguese case studies reported below.

Despite the potential benefits, the adoption of cover crops by the grape producers in Mediterranean non-irrigated vineyards has been limited by the concern of net loss of soil moisture through evapotranspiration by cover crops. This concern is increased in dry seasons (low winter-spring rainfall) were excessive water competition may occur (Pou et al. 2011; Lopes et al. 2011).

Trying to further elucidate cover crops competition with vine, in this paper data on water use and grapevine performance obtained in soil management experiments (inter-row soil tillage *vs.* resident vegetation), carried out in three different Portuguese terroirs, will be reviewed and discussed.

2 MATERIALS AND METHODS

Data presented in this paper was obtained in field experiments carried out at the Dão, Lisboa and Alentejo Portuguese winegrowing regions. Table 1 presents a brief description of each experiment and more detailed information can be obtained at Monteiro and Lopes (2007), Lopes et al. (2011) and Marques et al. (2016). Despite being multi-year experiments and of some differences in the experimental design and treatments, in this paper we only compare data from one season (3-4 years after cover crop establishment) and from two inter-row soil management practices (ST- soil tillage; RV -resident vegetation).

Soil and grapevine assessments were similar at the three experiments. Soil water content was monitored using a capacitance probe (Diviner 2000®, Sentek Pty Ltd) with readings taken periodically at increments of 0.1 m from soil surface to a depth of 1.0 (Lisboa and Alentejo) or 1.5 m (Dão). At harvest the cluster number and weight per vine were assessed and a berry sample per replication was collected to evaluate fruit composition. During winter pruning the shoot number and total pruning weight per vine was recorded.

Table 1 – Description of the site, vineyard characteristics and experimental design for each of the three case studies. ST – soil tillage; RV – resident vegetation; VSP – vertical shoot positioning.

Winegrowing region	Dão	Lisboa	Alentejo
Place	Nelas (40° 31'N, 7° 51'W)	Alenquer (39º 01' N; 9º 06'W)	Estremoz (38º 51' N; 7º 33'W)
Elevation (m)	440	150	350
Soil	Sandy	clay loam	silty clay loam
Variety/ rootstock	Touriga Nacional/ 110 R	Cabernet Sauvignon/ 110 R	Aragonez 1103 P
Vine spacing (m)	2.0 x 1.1	2.5 x 1.0	2.5 x 1.0
Training system	VSP, spur pruning	VSP, spur pruning	VSP, spur pruning
Experim. Design	Factorial 2x2	Randomized comp. block	Split-plot
Treatments	ST *vs. RV* x undervine mulch *vs*. herbicide.	ST, RV and sown cover crop.	ST *vs* RV x 3irrigation strategies
Seasons	2010-13	2002-04	2004-06
# mowing/tillage	2/2	2/2	2/1
Source	Marques et al. (2016)	Monteiro & Lopes (2007)	Lopes et al. (2011).

3 RESULTS AND DISCUSSION

3.1 Water use and dynamics

In all the 3 sites the winter and early spring rainfall was enough to allow the soil attain the field capacity at the beginning of the growing period (Fig. 1). After budburst, in all the 3 sites, the seasonal pattern of soil water content (SWC) displayed a decreasing trend throughout the growing season in both treatments, except for Alentejo after irrigation starting (end of May – flowering) where slight increases were observed as a consequence of irrigation events (Fig. 1c). At the beginning of the season, at all the sites, both treatments presented statistical similar SWC values. As the season progressed, RV treatments showed a trend to lower SWC than ST, differences that increased at late spring (Lisboa and Alentejo) and mid-summer (Dão). During the ripening period an opposite trend was observed in all the 3 sites which achieved harvest time with RV showing similar SWC to ST except for Lisboa site where RV maintained lower values but with smaller differences than those observed at the end of Spring (Fig.1b).

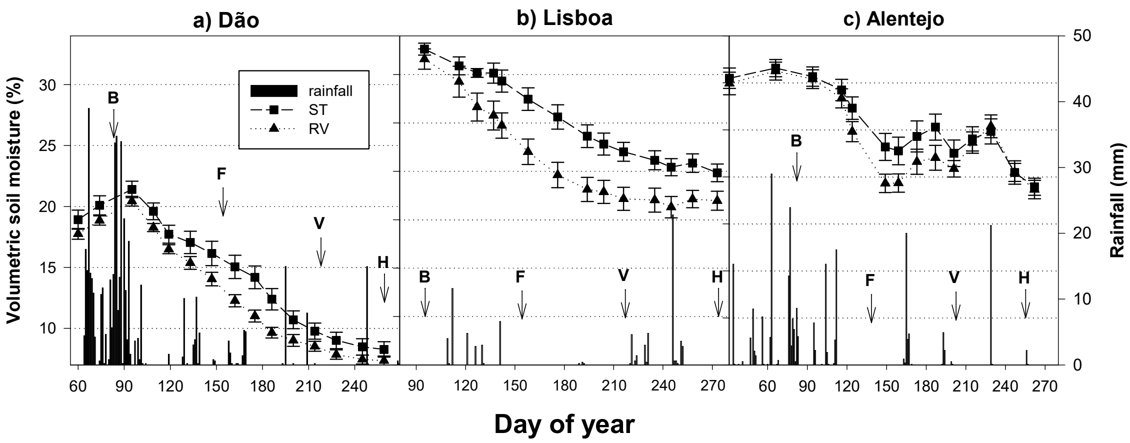

Figure 1. Effect of soil management practices on the seasonal pattern of soil water content measured <u>in situ</u> at the 3 experimental sites. Each point represents the mean and standard error of the measurements made on 8 (a), 12 (b) and 16 (c) access tubes. ST – soil tillage; RV – resident vegetation. B- budburst; F – flowering; V – veraison; H - Harvest

In order to estimate daily average water use, the amount of rainfall and the water depletion in monitored soil depth were calculated for the 3 main vine growth periods of the 3 sites (Table 2). At all sites, in the budbreak-flowering period, RV presented a significantly higher daily water use than ST. Between flowering and veraison the relative situation was inversed however only at the Dão site the differences were significant. During the ripening period and for all sites, the RV treatment presented lower daily water use values than those displayed by the ST treatment, however the differences were not significant for the Dão site. In all sites no significant differences were observed between treatments for total water use during the entire growing season (Table 2).

Table 2 - Effect of soil management practices on estimated average water use(*) over the three main grapevine growth periods for the winegrowing regions of Lisbon (Lx); Dão and Alentejo (Al). ST – soil tillage; RV – resident vegetation. R – rainfall; I – irrigation. Adapted from Monteiro and Lopes (2007); Lopes et al. (2011) and Marques et al. (2016).

	Daily water use (mm day^{-1})									**Total water use** (mm)		
Period	Budbreak-flowering			Flowering-veraison			Veraison-Harvest			Budbreak-Harvest		
Site	Lx	Dão	Al	Lx	Dão	Al	Lx	Dão	Al	Lx	Dão	Al
ST	1.58	2.33	2.09	0.95	1.85	2.60	1.18	0.78	2.02	221.8	312.9	343.5
RV	2.05	2.74	2.82	0.85	1.46	2.18	0.83	0.67	1.38	226.0	311.2	336.2
Sig.	*	*	**	*ns*	*	*ns*	*	*ns*	*	*ns*	*ns*	*ns*
R+I (mm)	187.8	63.8	55.5	0.8	35.2	117.1	45.6	14.9	72.0	234.2	113.2	244.6

(*) Sum of the rainfall with soil water depletion from 0-1.0 m (Lisboa and Alentejo) or 0-1.5 m (Dão) soil depth, assuming the absence of runoff, deep percolation and capillary rise of groundwater. Sig -Statistical significance given by (*) P = 0.05, (**) P = 0.01 and (ns) not significant.

The water used was not uniformly extracted from all the soil layers and the pattern of extraction changed with the sites and throughout the growing season. At the Dão site, from budburst to flowering soil water depletion has occurred mainly in the first 3 soil layers (0 to 0.9 m) with the RV treatment presenting significantly higher values than those of ST. During the flowering–veraison period there was a progressive tendency for more water depletion from deeper layers (0.9 – 1.5 m) and the relative situation between treatments was reversed. During the ripening period water extraction values were very low throughout the entire profile in both treatments (data not shown; Marques et al. 2016). Regarding the relative contribution of each layer in Dão site, while no significant differences were obtained during spring (Fig. 2A), during the flowering–veraison period, the surface layers (0-0.6 m) contributed with a significantly higher percentage of water in ST than in RV while the opposite was observed at the deepest layers (Fig. 2B).

At the Lisboa experiment, during the spring, while RV treatment showed an extraction of water which, albeit more intense in the upper layers, spanned the entire profile, ST presented a lower extraction from both upper and deep layers where almost no water was extracted. When computing the relative contribution of each layer during Spring, while no significant differences were obtained at surface layers (0-0.6 m) the deepest layer (0.6-1.0 m) has contributed with a significantly higher percentage of water in RV than in ST (Fig. 2C). Between flowering and veraison both treatments extracted water uniformly from all the soil layers and during the ripening period, while ST showed an almost uniform water extraction from all soil layers, in the RV treatment no water was extracted from the upper layer (0-30 cm) being the deeper layers the main contributors (data not shown; Monteiro and Lopes 2007).

Regarding the Alentejo experiment, during the spring (before irrigation), while in the RV treatment the water extraction was almost uniform from the entire 1.0 m profile, the ST presented higher extraction from the 2 upper layers (0-0.3; 0.3-0.6 m) than from the deeper one (0.6-1.0 m). Concerning the relative contribution of each layer during the same period, the surface layer (0-0.3 m) contributed with a higher percentage of water in ST than in RV while the opposite was observed at the deepest layer (Fig. 2D).

3.2 Impact on vine vegetative growth, yield and berry composition

The effects of cover crops on vine performance were different in each terroir. At Dão region, despite a slightly higher (not significant) pruning and shoot weight presented by ST treatment, no significant differences were detected on yield and berry composition (data not shown; Marques et al. 2016). At the Lisboa region, while no significant effect was detected in yield, a significant reduction in vine vegetative

growth was observed in RV treatment as compared to ST. This induced a positive effect on grape composition by increasing berry skin total phenols and anthocyanins (data not shown; Monteiro and Lopes, 2007).
At Alentejo, the higher water used by the cover crops in spring (before irrigation starting) induced an earlier stop in vine shoot growth as compared to the vines growing under soil tillage. This has induced a significant decrease in vine pruning weight (shoot weight attained values near the lower limits of the optimal vigor and vine balance range), berry weight and yield without any compensation on berry composition as compared to the ST (data not shown; Lopes et al. 2011).

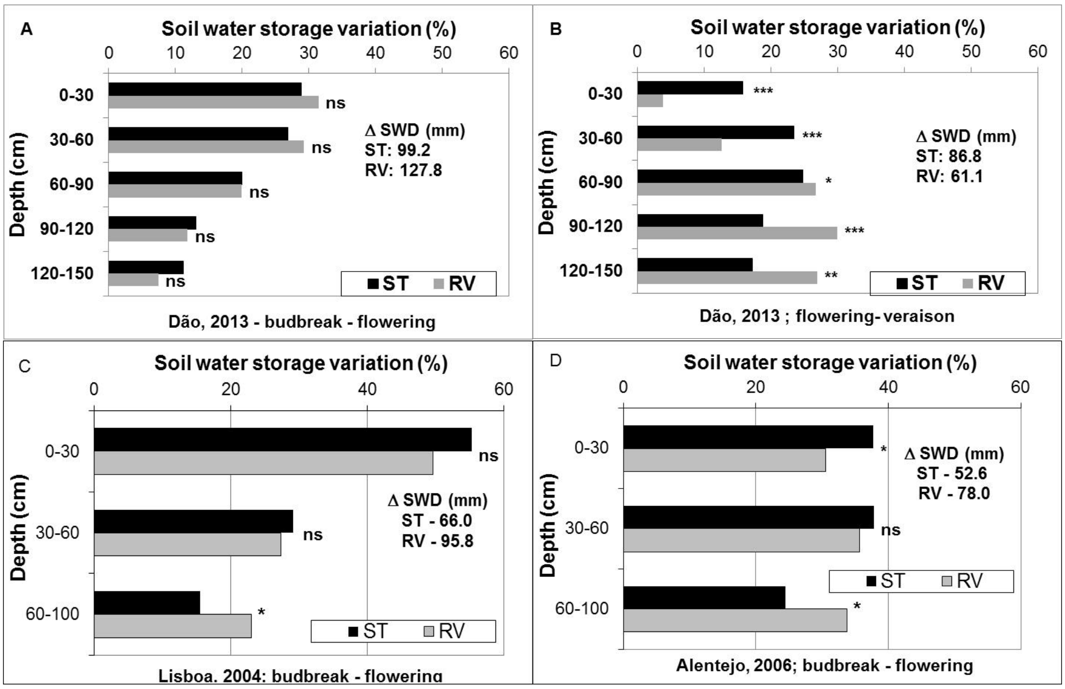

Figure 2. Effect of soil management practices on estimated mean percent soil water storage variation in different soil layers for the growth periods of budbreak-flowering (A, C & D) and flowering- veraison (B) for the 3 sites: winegrowing regions of Dão (A &B), Lisboa (C) and Alentejo (D). ST – soil tillage; RV – resident vegetation. SWD – soil water depletion. Statistical significance given by (*) P = 0.05, (**) P = 0.01, (***) P = 0.001 and (ns) not significant.

4 DISCUSSION AND CONCLUSIONS

Our results show that vineyard cover cropping is a very effective tool for manipulating soil water availability in Mediterranean-type climates. In the 3 experiments water competition by cover crops was much more pronounced during Spring as also reported by several authors (e.g. Tesic et al. 2007, Cellete et al. 2008, Cellete and Gary 2013). After flowering the differences in water use between the two soil management treatments disappeared or were reversed. This behavior can be explained by a larger evapotranspiration in ST caused by the combination of higher vine leaf area and the likely higher soil evaporation that is to be expected from bare soil. The likely lower soil evaporation caused by the mulching effect of cover cropping residues that dried out in RV can also contribute to attenuate the differences in water use between the two treatments during the ripening period (Skrotch and Shribbs 1986, Prichard 1998, Guerra and Steenwerth 2012). The total water use for the entire season showed no significant differences between treatments for all the 3 sites, however these results should be looked at with care as possible water uptake from deeper (non-monitored) soil layers could also contribute to explain the absence of differences in total water use between soil management practices.
Besides the differences in water use, in all the 3 sites, the two soil management treatments presented different patterns of water extraction through the monitored profile with RV showing higher values at deep soil layers than the tillage treatment. This behavior was also reported by other authors (e.g. Morlat and Jaquet 2003; Celette et al. 2008) who stated that the competition between the resident vegetation and the vine reduces the number of vine roots in the inter-row but induces the development of a deeper root system in the vine row in order to explore the more wetted layers. It is likely that a similar behavior has occurred in our experiments, explaining the higher water depletion observed in the deeper soil layers on the RV as compared to ST treatment.

The impact on vine performance was terroir dependent. Under the ecological conditions of the Dão terroir, the use of resident vegetation seems to be a good alternative to soil tillage since the water competition observed in the spring was not severe enough to negatively affect grapevine vegetative and reproductive growth neither berry composition. So, in this terroir the use of cover crops may be a useful technique to provide the benefits of biodiversity enhancement and weed suppression and to reduce inter-row tilling and herbicides applications without a negative impact on vine vigor and yield and on wine quality. However more robust conclusions can only be drawn after the full analysis of the 5 seasons data of this experiment, which is under progress (Marques et al. 2016).

At the vigorous vineyard of Lisboa experiment (Atlantic influence; deep clay soil), the water competition by the RV treatment induced a favorable reduction in vine vegetative growth, which had a positive effect on grape composition as compared to ST, results similar to the ones reported by Caspary et al. (1997), Wheeler (2005) and Giese et al. (2015). These results indicate that cover cropping can be a valuable tool for controlling vigour and enhancing wine quality in this winegrowing region.

An opposite situation has occurred at the Alentejo experiment where the higher water use by the RV treatment in Spring has induced a negative impact on vine vigor and yield without any compensation in berry composition. This reduction of vine vegetative growth in RV as compared to ST has been mainly attributed to the competition for water (Celette et al. 2005; Tesic et al. 2007, Lopes et al. 2011, Pou et al. 2011). Nevertheless, other studies using cover crops showed that the reduction in nitrogen uptake and storage in aerial parts can also contribute for reduced vine shoot growth (Maigre and Arny 2001; Wade et al. 2004; Celette et al. 2009). However no significant differences were detected in leaf nitrogen content between the two treatments (Lopes et al. 2011) enabling to conclude that the observed negative effect on shoot growth was mainly due to the competition for water by the cover crops.

Summarizing, the use of cover crops is a vineyard management practice that can have a positive influence on water use efficiency, either by preventing vine excessive vigor when water is fully available during spring or by maximizing the volume of soil explored by roots through the enhancement of the exploitation of soil water reserves into deeper layers. However, in the case of low vigor vineyards located in dry terroirs, the degree of water competition between cover crops and vine must be carefully monitored and managed (e.g. by selecting less competitive cover crop species, increasing mowing frequency, and/or reducing the area covered by the swards). Furthermore adjustments in conventional irrigation management are necessary in order to avoid detrimental effects on grapevine yield and vigor.

Future research needs include long-term detailed trials to provide further knowledge on the consequences of cover cropping on vine water use efficiency, vigor, yield and wine quality for a particular '*terroir*'.

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