Ciência Téc. Vitiv. 27 (1) 27-38. 2012

SOIL MANAGEMENT: INTRODUCTION OF TILLAGE IN A VINEYARD WITH A LONG-TERM NATURAL COVER

MANUTENÇÃO DO SOLO: INTRODUÇÃO DE MOBILIZAÇÃO DO SOLO NUMA VINHA COM ENRELVAMENTO NATURAL DE LONGA DURAÇÃO

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(Manuscrito recebido em 24.05.2012. Aceite para publicação em 19.06.2012)

SUMMARY

A study was carried out during two years (2004 and 2005) at Bairrada Delimited Region (littoral/centre of Portugal) with the white cultivar "Fernão Pires" for the evaluation of the effects of tillage application in a non-irrigated commercial vineyard with a long term natural cover crop. In the two years of the experiment, during the growing season the climate was dry, especially in 2005. Consequently, a moderate to severe water stress was observed during ripening,, although little differences between natural grass covered and tilled treatments were found, according to predawn leaf water potential evolution. Vine nutritional status was also improved by tillage and, therefore, higher net photosynthetic rates were verified.

Tillage induced higher vegetative growth, particularly on lateral shoots that led to a denser and more shaded canopy. Hence bunch rot (*Botrytis cinerea* Pers.) intensity was significantly higher in the tilled treatment in 2004 due to important rainfall events in summer. However, in hot and dry summers, as in 2005, higher vigour induced by tillage was crucial to reduce bunch sunburn injuries.

The yield was significantly increased in 2005 in tilled treatment (around 100%) because of higher fertility index, which result from the better nutritional status and vigour of previous year, bunch and berry weight, and also from the decrease of sunburn injuries. Lower effects of treatments were observed in the must composition. In 2005, even with a strong yield increase caused by tillage, the soil management techniques did not influenced the nutritional must composition.

RESUMO

Para a avaliação dos efeitos da mobilização do solo numa vinha comercial não regada com enrelvamento natural de longa duração foi efetuado um estudo durante os anos de 2004 e 2005, na Região Demarcada da Bairrada (Litoral-Centro de Portugal) na casta Fernão Pires.

Durante os dois anos de ensaio, o clima foi seco ao longo do ciclo vegetativo, especialmente em 2005. Consequentemente foram verificadas intensidades moderadas a severas de stress hídrico durante o período de maturação. Contudo, de acordo com a evolução do potencial hídrico foliar de base, apenas foram verificadas diferenças ligeiras entre os tratamentos enrelvado e mobilizado. O estado nutricional da vinha foi também melhorado pela realização da mobilização do solo e, como consequência, verificaram-se taxas fotossintéticas líquidas superiores.

A mobilização do solo induziu um crescimento vegetativo mais elevado, particularmente ao nível das netas, o que conduziu a um copado mais denso e ensombrado. Como consequência, em 2004 e devido à precipitação ocorrida no verão, os níveis de podridão das uvas (*Botrytis cinerea* Pers.) foram significativamente mais elevados no tratamento mobilizado. Pelo contrário, num verão quente e seco, como o de 2005, o vigor induzido pela mobilização do solo foi fundamental na redução do escaldão dos cachos.

O rendimento aumentou significativamente em 2005 no tratamento mobilizado (cerca de 100%) devido ao maior índice de fertilidade, consequência do melhor estado nutricional e do vigor no ano anterior, ao maior peso do bago e do cacho e também devido à redução do escaldão dos cachos. Apenas ligeiras diferenças foram verificadas na composição dos mostos. Em 2005 e apesar do forte aumento do rendimento induzido pela mobilização do solo, a composição nutricional do mosto não foi afetada pelas técnicas de manutenção do solo.

Key words: soil management, cover crops, tillage, canopy structure, yield, fruit composition.
Palavras-chave: manutenção do solo, culturas de cobertura, mobilização, estrutura do coberto, rendimento, composição das uvas.

INTRODUCTION

Vineyard cover cropping is a practice that had a growing development in recent decades, aiming at reducing soil erosion, maintain or improving soil fertility, control the vegetative vigour and excessive yield, often associated with phytosanitary problems and low quality.

The benefits of cover cropping are not yet fully proven. The results are often controversial and difficult to extrapolate due to the soil type's variability, the climatic conditions and the cover crops composition and/or management. In recent years the effects of cover crops in vineyards have been evaluated at several levels.

One of the most relevant effect of cover crops is the mitigation of soil erosion, particularly in hill slopes. Indeed, these crops can contribute to reduce the impact of raindrops, to improve soil organic matter, structure and infiltration rates and also to reduce runoff (Battany and Grismer, 2000; Hartwig and

Ammon, 2002; Ruiz-Colmenero *et al.*, 2011). These effects are most evident in Mediterranean climates owing to the rainfall concentration in winter, when the soil surface is more exposed.

Several studies have been performed on the availability of nutrients, namely grass cover nitrogen (N) competition (Rodriguez-Lovelle *et al.*, 2000; Celette, 2007; Celette *et al.*, 2009), legume N fixation (King and Berry, 2005; Ovalle *et al.*, 2010) and winter N scavenging (Sainju *et al.*, 1998; Tournebize, 2001). According to Keller (1997) and Morlat and Jacquet (1993) the grass cover can contribute to an increase of the permutable potassium.

The most problematic issue associated with the cover application in vineyards is the competition for water. The importance of appropriate cover crops species and the control of some weed species was emphasize by Lopes *et al.* (2004). These authors estimated potential transpiration rates between 1 and 5 mm day^{-1} for different cover species. Also for spontaneous cover crops, the actual maximum evapotranspiration can vary between 3 and 4.5 mm day^{-1} according to the year (Tournebize, 2001). Monteiro and Lopes (2007) found an increase in vineyard's water consumption of 0.5 mm day^{-1} due to cover crops when compared with soil tillage. Cover crops with adequate moisture control can regulate vine growth and contribute to optimize the quality of wine. Afonso *et al.* (2003) verified a 20% reduction in the vine vigour due to the application of cover crops in a region with an annual rainfall of 1200 mm, during a three years study. Improvements in grape and wine quality resulting from cover crops use were also found in other works (Celette, 2007; Monteiro and Lopes, 2007; Xi *et al.*, 2011).

According to Howell *et al.* (2007), the soil compaction due to continued machinery traffic in the vineyard, associated with non-tilling, inhibits the root growth in the mid row, reducing plant ability to explore water resources and, consequently, presents a negative effect on yield and quality.

In spite of many works performed on the effect of cover crops in vineyards, there is a lack of long-term studies on this subject. Moreover, very little research has been done to investigate the conversion of cover crop to tillage. Thus, the purpose of this study was to determine the effects on the ecophysiology, canopy microclimate, yield and fruit composition of tillage application to a vineyard submitted to a long period with natural cover crop. This study was done at Bairrada region (Central Portugal), were traditionally vineyards are strongly and deeply tilled (Castro *et al.*, 1999), with the cultivar Fernão Pires (syn. Maria Gomes), the most cultivated Portuguese white vine variety. This cultivar is very productive, with a downward position and has an early budburst, making it very sensible to late spring frosts. It is resistant to powdery mildew, but sensible to downy mildew and bunch rot (Eiras-Dias *et al.*, 2011).

MATERIAL AND METHODS

Experimental site

The trial took place at a vineyard that belongs to the company Sogrape Vinhos, SA, located in Bairrada Delimited Region (40º25'41''N; 8º30'05''W), during 2004 and 2005. The grapevines (*Vitis vinifera* L. cv Fernão Pires, grafted on SO4 (*Vitis berlandieri* x *Vitis riparia*) were planted in 1987 and spaced 1.25 m within rows and 2.5 m between rows (i.e. 3200 vines ha^{-1}). Row orientation is North-South. Vines are trained on a spur pruned bilateral Royat Cordon, with vertical shoot positioning and a crop load of 20 buds per vine. The soil has a permanent natural grass cover (resident flora), which composition is described on Table I, and wasn't tilled for more than 10 years.

According to Thornthwaite hydric balance, the climate in this region, is fairly humid, mesothermic, with a moderate lack of water in summer and meanly tempered and rainy in the winter (Castro *et al.*, 1999), and according to Köppen-Geiger climate classification (Kottek *et al.*, 2006) is Csb (warm temperate with dry and warm summer). The annual rainfall average is 1010 mm.

The weather data was collected from an automatic meteorological station, placed in the vineyard, which assessed data from temperature, atmospheric relative humidity, wind speed and rainfall.

According to Cardoso (1974) the vineyard is planted in a litholic non-humic soil and has an AhBwC pedologic profile. The soil has a sandy-loam texture, is neutral (pH H_2O = 7) at the 0-20 cm level and moderately acid at 20-50 cm (pH H_2O = 6) and the organic matter content is medium (3.5%). This assessment has been done immediately before the trial.

The experimental design was a randomized complete block with two treatments and two replications per treatment. Each experimental unit had four rows with 100 vines each, and all the data was collected on the two inner rows.

Soil Management Treatments

Two soil management techniques were tested: Soil Tillage (TIL) – three times along the cycle (early April, middle May and end of June) with a scarifier at 20 cm depth; Natural Grass Cover (NGC) – where the permanent natural grass cover was mowed twice a year (early May and end of June) with a flail mower.

To weed control on the row, a foliage systemic herbicide was applied in both treatments. The application on each side of the row on 40 cm strip (gliphosate, 360 $g.L^{-1}$, 2.5 $L.ha^{-1}$) was done before budburst, by a tractor with an herbicide bar.

Floristic survey

Throughout the cycle of 2005 three floristic surveys were assessed only at NGC, on April 8th, September

2th and November 4th. The biomass above ground from each plant species was harvested by cutting plants at soil surface level inside a circular 0.5 m2 area (6 samples per replication).

After field sampling, each plant was identified and catalogued. Plants were counted to determine its relative frequency.

Nutritional analysis

A nutritional characterization of vines was made at full-bloom in both years. Two petioles samples (50 petioles) were taken from each treatment replication. One leaf per vine was collected from the opposite side of the lower cluster of a central spur of cordon, according to the procedure proposed by Pacheco *et al.* (2001).

At the harvest of 2005, a sample of 50 clusters (1 per plant) from each treatment was collected to perform the nutritional characterization of grapes.

Gas exchanges and leaf water potential measurements

Vine leaf temperature and photosynthesis rate were carried out near and during the ripening in both years, with a portable gas exchange system (model ADC-LCA4). Measurements were done three times a day (10 am, 2 pm and 6 pm) in 12 principal exposed leaves, from the middle part of the canopy, per soil management technique (six per replication).

Leaf water potential measurements (ψf) were done with a pressure chamber (Manofrígido, Lda.), as described by Scholander *et al.* (1965) at predawn, 10 am, solar noon and 6 pm. In each treatment were measured 12 principal exposed leaves (6 per replication), from the middle part of the canopy.

Canopy Structure

Close to veraison, 24 shoots per treatment (one normal, average and fruitful shoot per vine) have been selected to assess leaf area, using the methodology proposed by Lopes and Pinto (2005).

The canopy density was assessed by the leaf layer number, according to the method "Point Quadrat" proposed by Smart and Robinson (1991), making 120 insertions at the cluster height, in each treatment. The evaluation of the canopy density was done during ripening.

The evaluation of the interception of Photosynthetic Active Radiation (PAR) by the canopy, was performed using a ceptometer (SunScan Ceptometer-type SS1 - Delta-T Devices) inside the cover, in the cluster zone, during ripening. The ceptometer was inserted into the canopy, parallel to the row and to the ground, 100 times per treatment.

Fertility, yield and vigour

The total shoot number per vine and the number of clusters from each shoot were counted in 120 vines (60 per treatment) in the spring of 2005, in order to assess fertility.

To evaluate the yield, it was assessed the number of clusters per vine and their weight in 100 vines per treatment at harvest.

To assess the vine vigour, the shoots number and their weight per vine was registered in the same 100 vines per treatment used to calculate the yield.

Bunch-rot and sunburn evaluation

To evaluate bunch rot (*Botrytis cinerea*, Pers.) intensity, one bunch per vine (120 vines per treatment) was observed at harvest to determine the incidence (infected bunch number) and the severity (destroyed portion of the bunch) of the infection, using the methodology purposed by Amaro and Raposo (2001).

At harvest, in each of the selected vines (120 per treatment), all the sunburned clusters were counted to assess sunburn damage proportion.

Data analysis

The analysis of results related to the behaviour and ecophysiological behaviour (predawn leaf water potential, photosynthesis and transpiration rate) were corrected by the average standard error with M.O. Excel. Statistical analysis was done by analysis of variance using Statistica 6.0 software.

RESULTS AND DISCUSSION

Climate

The climatic conditions along the two years of the experiment were quite different (Fig. 1). The monthly average temperature during 2004 was normal for the region, and only in June it has been significantly higher than the 30 years average (1967-1996). In 2005 and during the vine vegetative cycle, the mean temperature was higher than the 30 years average.

Concerning the rainfall, in both years, October had higher relative precipitation than the average (70 mm above), while the other months were less rainy than it. In the winter of both years the rainfall was significantly lower than the average, and the total volume of precipitation before bud burst (between October and March) was 485 mm in 2004 and 340 mm in 2005, both of them less than the average (722 mm). During the growing season, similar values of rainfall (137 mm in 2004 and 108 mm in 2005) were observed in both years. However, spring rainfall was around 120 mm below the average in both years.

Natural grass cover characterization

Table I presents the frequency distribution of each species on natural grass cover during 2005. In all

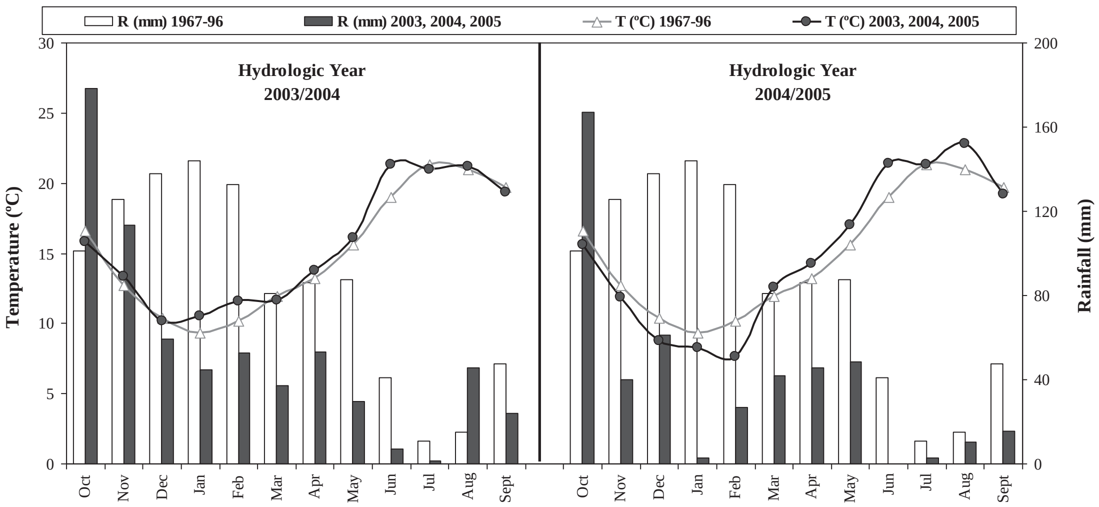

Figure 1 – Rainfall and average temperature during the 2 hydrological years trial compared with the average of 30 years (1967-1996).
Precipitação e temperatura médias de 2004 e 2005 em comparação com média de 30 anos (1967-1996).

data collection the dominant specie is *Holcus lanatus* L. This gramineous is a rhizomatous and perennial species, which forms a grass cover that difficult the development of other species. Although, in this trial field this is a spontaneous species, Amaro *et al.* (2001) referred it as a preferential species to install grass covering on vineyards.

It can also be observed that, in the first two evaluations, the soil dry conditions inhibited germination and establishment of legumes, herefore, grasses had better emergence rates (perennial grasses were 88% and 97% in the first and in the second assessments, respectively). After the first rainfalls in autumn, the proportion of other families, including legumes, strongly increased up to 67% of cover crop. Similar results were found by Olmstead *et al.* (2001).

The almost complete absence of legumes in the first evaluations can also be associated with the soil management system effects on species frequency distribution (Gago *et al.*, 2007). In this case study,

TABLE I

Frequency distribution of cover crop species, on three dates, during the 2005 vegetative cycle.

Percentagem de biomassa das espécies constituintes do enrelvamento natural, em três datas, durante o ciclo vegetativo de 2005.

	Family	Cycle	% of Number		
Specie		**(Annual/Perennial)**	**08-Jun**	**02-Set**	**04-Nov**
Andryala integrifolia L.	*Asteraceae*	Annual		2.86	
Coleostephus myconis L.	*Asteraceae*	Annual	1.30		
Sonchus oleraceus L.	*Asteraceae*	Annual			1.26
Rhaphanus raphanistrum L.	*Brassicaceae*	Annual			1.55
Sinapsis arvensis L.	*Brassicaceae*	Annual			0.10
Polycarpon tetraphyllum L.	*Caryophyllaceae*	Annual/Biannual			9.28
Spergularia purpurea (Pers.)G.Don.fil.	*Caryophyllaceae*	Annual/Biannual			2.51
Convolvulus arvensis L.	*Convolvulaceae*	Perennial			0.39
Erodium moschatum (L.) L´Hér.	*Geraniaceae*	Annual			23.31
Geranium molle L.	*Geraniaceae*	Annual			15.67
Hypericum humifusum L.	*Hypericaceae*	Perennial	1.30		
Ornithopus compressus L.	*Leguminosae*	Annual			10.83
Trifolium campestre Schreber	*Leguminosae*	Annual/Biannual	2.60		
Trifolium resupinatum L.	*Leguminosae*	Annual	2.60		2.03
Lavatera cretica L.	*Malvaceae*	Annual/Biannual	1.30		0.10
Malva sylvestris L.	*Malvaceae*	Annual/Biannual	1.30		
Cynodon dactylon L.	*Poaceae*	Perennial		19.05	
Holcus lanatus L.	*Poaceae*	Perennial	88.31	76.19	20.02
Lolium multiflorum Lam.	*Poaceae*	Annual		1.90	
Poa annua L.	*Poaceae*	Annual			12.67
Rumex crispus L.	*Polygonaceae*	Perennial	1.30		
Rumex pulcher L.	*Polygonaceae*	Perennial			0.29

Holcus lanatus L. and *Cynodon dactylon* L. were privileged for the reason they tolerate mowing due to their basal buds or underground regeneration organs (Beuret and Neury, 1987).

Nutritional characterization

The vineyard nutritional characterization was made at full bloom (Table II). The interactions between cover crop and soil/plant nutritional status are complex and dynamic due to the diversity of cover crop types and management. The effects of tillage on nutritional status was evaluated every year at full bloom, by the analysis of leaf petioles (Table II) that is more useful and reliable than soil analysis because the results represent the concentration of nutrients that grapevines are able to remove from soil (Hirschfelt, 1998).

A significant effect on nitrogen (N) petioles concentration was verified only in the first year, with an increase of N concentration due to tillage. We could expect from the decomposition of cover crop (non legume) residues with a probably high C/N ratio, an immobilization of soil N for several weeks to months after incorporation on soil (Hirschfelt, 1998). However, in this case, at full bloom (one month after the first tillage), N levels were already different between soil management options, due to the intense mineralization of the soil stable organic matter in upper layers of the soil, right after tillage (Steenwerth and Belina, 2008; Curtin *et al.*, 2010). On the other hand, the release of N from cover crop depends on species, growth stage, management and climate (Dabney *et al.*, 2001). Also, non legume cover crop competition for N with the main crop is a well know phenomenon and was verified in vines in Mediterranean climates (Celette *et al.*, 2009).

TABLE II

Influence of soil management on leaves nutritional composition, at full bloom in 2004 and 2005. Values are expressed in g by kg of dry matter.

Influência da manutenção do solo na composição nutricional das folhas, à plena floração em 2004 e 2005. Valores expressos em g por kg de matéria seca.

Year	Soil management	N	P	K	Ca	Mg	K/Mg
2004	**NGC**	7.3	2.6	31.4	24.3	3.0	10.7
	TIL	10.1	2.8	30.5	31.1	3.1	10.0
	Sig.	*	*n.s.*	*n.s.*	*n.s.*	*n.s.*	*n.s.*
2005	**NGC**	8.1	3.0	41.0	27.4	2.4	18.0
	TIL	8.1	2.4	31.5	27.1	3.5	10.7
	Sig.	*n.s.*	*n.s.*	*n.s.*	*n.s.*	*	*n.s.*
	Recommended values	9-12	2-4	15-25	14-28	2,5-5	4-8

Sig. – Significance level; n.s. – non significant at 5% level by F test; significant at 5% level (*) by F test. NCG – Natural Grass Cover; TIL – Tillage.

In 2005 similar N levels were found in the two treatments. According to Curtin *et al.* (2010), the N mineralization increase, due to tillage on traditionally non-tilled soils, only in the early stages after the intervention. After this first phase, the mineralization rate tends to decrease and equalize to that of non-tilled soils.

In general, in 2005, the nutrient levels are within the range of recommended values (Cavaco *et al.*, 2005). We can highlight the nitrogen (N) and magnesium (Mg) contents, which are close to the lower limits in both treatments. On the other hand, potassium (K) is above the recommended values in both treatments, especially in NGC. Higher levels of K in this treatment suggest a low absorption of Mg due to antagonism phenomenon between these nutrients (Quelhas-dos-Santos, 1996), which is shown by the unbalanced K/Mg relationship.

In spite of the few works on the effects of cover crop on the status of other grapevine nutrients, the increase of K availability in the soil with cover crop has been referred by Morlat and Jacquet (1993) and Baumgartner *et al.* (2008). Tesic *et al.* (2007) also verified a significantly reduction of Mg uptake due to cover crops. Although not statistically significant, there appeared to have a similar trend in this study that led to a greater unbalance in the K/Mg relationship in natural grass cover treatment in 2005.

At harvest, contrarily to what was observed by other authors (Geoffrion, 1999; Chantelot *et al.*, 2001; Celette, 2007), no significant differences on the nutritional composition of grapes were found as a consequence of different soil management techniques, (Table III), in spite of the differences in the grape yield.

Leaf water potential and gas exchanges

The influence of soil management techniques on vineyard water status was evaluated by the predawn leaf water potential (Ψ_{pd}). For this variable, which reflects the water potential of the whole soil volume exploited by the vineyard roots, there are consistent and robust threshold values (Carbonneau, 2001; Ojeda, 2001; Riou and Payan, 2001; Deloire *et al.*, 2003).

Thus, the evolution of Ψ_{pd} is presented in Figure 2 for the period between bloom and harvest in both years. The differences between years can be partially explained by the meteorological conditions occurred, namely the rainfall during August 2004 and the warmer temperatures during 2005.

the end of the maturation period due to the rainfall occurred in August (about 50 mm).

In 2005, small differences were found in mid-July.

TABLE III

Influence of soil management on grapes nutritional composition at harvest in 2005.

Influência da manutenção do solo na composição nutricional à vindima em 2005.

Soil management	mg/100 g of grapes										
	N	**P**	**K**	**Ca**	**Mg**	**S**	**Fe**	**Mn**	**Zn**	**Cu**	**B**
NGC	122.2	21.1	208.0	31.8	8.2	25.7	0.65	0.14	0.11	0.34	0.13
TIL	120.7	19.1	206.0	29.2	7.4	23.0	0.50	0.12	0.10	0.16	0.19

NCG – Natural Grass Cover; TIL – Tillage.

It can be seen that in 2004 no differences were found between the two treatments. Similar results were reported by Afonso *et al*. (2003) with Alvarinho cultivar in an Atlantic climate region (Vinhos Verdes). It is also observed that Ψ_{pd} never reached values of severe water stress, Ψ_{pd} decreased from the middle of June to the end of July, and no water stress was verified at At this time, NGC treatment showed a more intense water stress due to the NGC transpiration. Similar results were reported by Monteiro and Lopes (2007) that verified a bigger reduction on soil water content profile (0 – 1.0 m) from budbreak to veraison due to the CC water use. However, at veraison both treatments reached similar moderate to severe water stress

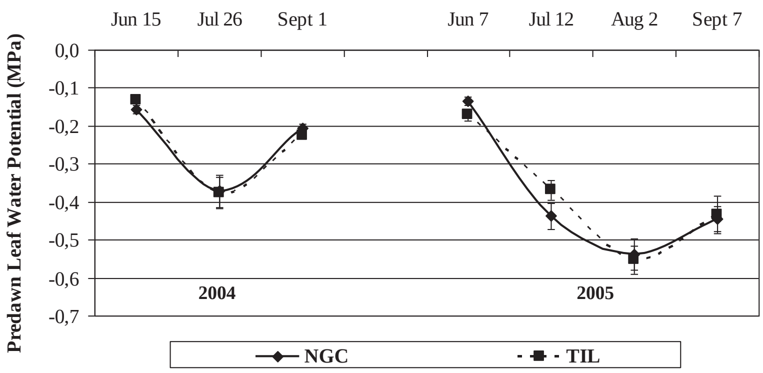

Figure 2 – Seasonal predawn leaf water potential evolution in 2004 and 2005. Average of 12 leaves ± SE. NCG – Natural Grass Cover; TIL – Tillage

Evolução sazonal do potencial hídrico foliar de base, em 2004 e 2005. Média de 12 folhas ± EPM. NCG – Natural Grass Cover; TIL – Tillage

levels. This fact is remarkable since Fernão Pires is a very aromatic cultivar and known by its sensibility to water stress (Eiras-Dias *et al.*, 2011). The rainfall occurred in early September (around 8 mm) allowed some recovery of plant water status.

The small differences found were surprising because tillage induced higher vine vigour (almost twice in 2005) and total leaf area (almost 50% more in both years) and, consequently, higher vine transpiration.

In spite of the vine ability to adapt the root system in order to access deeper water resources in deep soils due to the CC competition (Cellete *et al.*, 2008), as is the case of this study, were tillage was introduced after a long term NGC, tillage also improve vine water use, eliminating weed transpiration and creating macro and mesoporosity in the top soil layer while breaking pore continuity below (Cameira *et al.*, 2003) with the consequent decrease of soil evaporation.

Tillage significantly influenced the net photosynthetic rate (A) - Figure 3. It is evident that in both years, except for September 12th of 2004, the leaves from natural grass cover treatment presented higher temperature and lower photosynthetic rate In general, during 2004, differences between the two treatments were significant but not as high as in 2005. It can also be observed a trend to the decline of photosynthetic rate along the vegetative cycle, which can be partially ascribed to the age of leaves and the stage of the

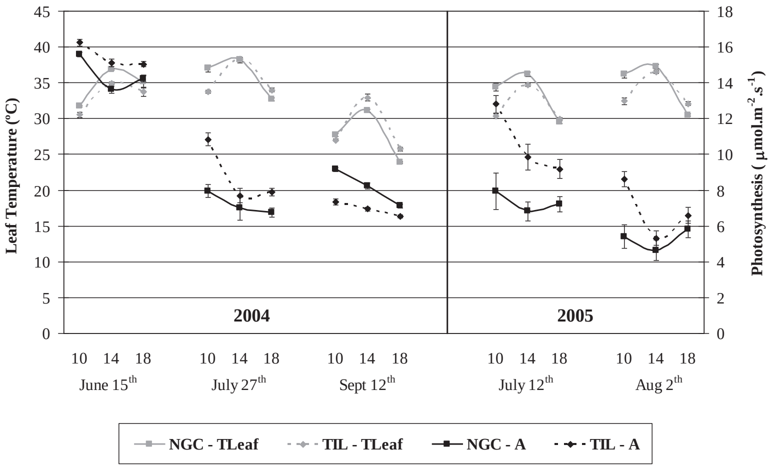

Figure 3 – Diurnal and seasonal evolution of net photosynthesis and leaf temperature, in 2004 and 2005. Average of 12 leaves ± SE. NCG – Natural Grass Cover; TIL – Tillage

Evolução diurna e sazonal da taxa fotossintética e da temperatura das folhas, em 2004 e 2005. Média de 12 folhas ± EPM. NCG – Enrelvamento natural; TIL – Mobilizado

growing season (Zuffery *et al.*, 2000).

Except for June 15th of 2004, photosynthetic rate was in the same range verified by Chaumont *et al.* (1997) and Lopes (1999) with the same grape cultivar. However, A rate observed by Lopes (1999) in an irrigation trial was lower, although similar predawn leaf water potential levels..

The highest differences between soil management treatments occurred in July 12th (2005). This is in agreement with Ψ_{pd} evolution. Moreover, different trends for leaf water potential were found (Figure 4). At July 12th, the minimum Ψ (Ψ_{min}) occurred in the tillage treatment at solar noon. However, for August 2nd, Ψ_{min} occurred sooner and remained constant until late afternoon, suggesting a strong stomatal control due to water stress. At this date differences between A for the soil treatments were smaller and photosynthetic rate reached relative low value, although leaves present similar temperature.

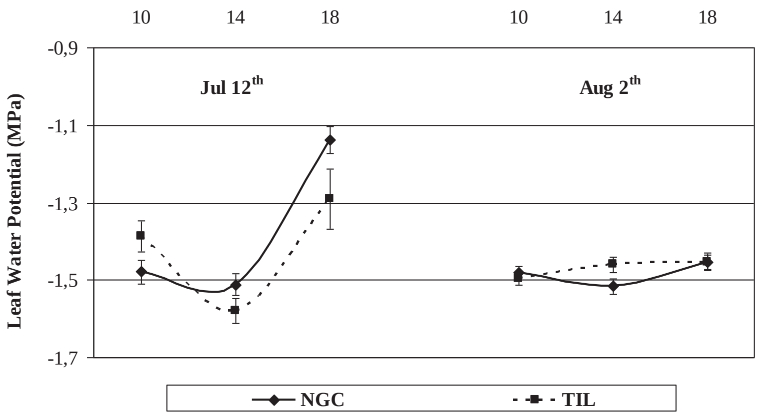

Figure 4 – Diurnal leaf water potential evolution in 2005. Average of 12 leaves ± SE. NCG – Natural Grass Cover; TIL – Tillage

Evolução diurna do potencial hídrico foliar, em 2005. Média de 12 folhas ± EPM. NCG – Enrelvamento natural; TIL – Mobilizado

The small differences in Ψ_{pd} suggest that the nutritional unbalance may also contribute to the differences verified on photosynthetic rate. In addition, the lower photosynthetic rates, as is the case of NGC, can be attributed to a limitation caused by an inadequate demand for photosynthates (Petri *et al.*, 2000).

Canopy Structure

Data analysis of whole plant leaf area in 2004 and 2005 (Figure 5) shows that total leaf area was increased by tillage (plus 1.97 m^2 of leaf area per vine in 2004 and 2.32 m^2 in 2005). In 2004 this increase was essentially due to the secondary leaf area (plus 1.89 m^2 of lateral leaf area per vine). In 2005 the principal leaf area have also contributed for it (plus 0.51 m^2 of principal leaf area per vine), although the major role played by the lateral leaf area (plus 1.81 m^2 of lateral leaf area per vine). Maigre and Aerny (2000) have also observed that lateral leaf area played a main

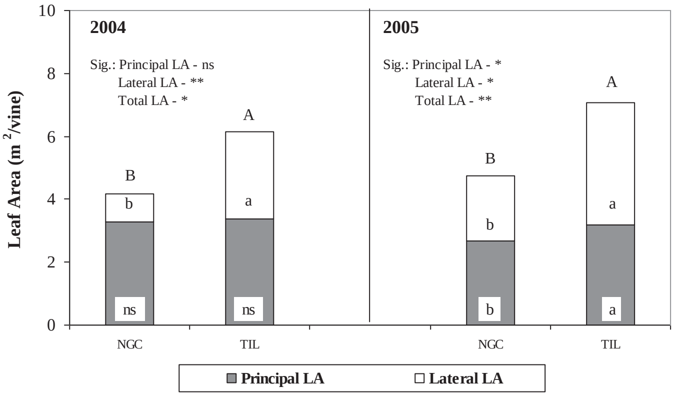

Figure 5 – Leaf area (principal, lateral and total) in 2004 and 2005. Average of 24 shoots. Sig. – Significance level; n.s. – non significant at 5% level by F test; significant at 5% (*), 1% (**) and 01% (***) by Tukey HSD test. NCG – Natural Grass Cover; TIL – Tillage.

Área foliar (principal, secundária e total) em 2004 e 2005. Média de 24 folhas. Sig. – Nível de significância; n.s. – não significativo ao nível de 5% pelo teste de F; significativo a 5% (*), 1% (**) e 0,1% (***) pelo teste de Tukey HSD. NCG – Enrelvamento natural; TIL – Mobilizado

role in the differences of total leaf area between soil management techniques in the cultivar Gamay.

The contribution of lateral leaf area for whole plant leaf area was higher on tilled soils in two growing seasons. Similar results were observed by Celete (2007) with the white variety Aranel in Mediterranean conditions.

The results of "Point Quadrat" method determined during the ripening in the 2005 growing season are shown in the Table IV. The soil tillage significantly increased the leaf layer number (LLN) and consequently reduced the light interception at cluster zone. Other authors found a minor canopy density (lower LLN) in a permanent cover cropped soil when compared to a bare soil (Celete, 2007; Tesic *et al.*, 2007). The main cause for these differences was the general increase of the vigour provoked by the tillage, especially due to the greater development of laterals, as reported above. In fact, many authors (Morlat and Jacquet, 1993; Morlat and Geoffrion, 2000), some of which Portuguese (Afonso *et al*, 2003; Monteiro and Lopes, 2007) observed a decline in the vine vigour with the introduction of cover crops when compared with tilled soils, probably due to the competition for the water and nutrients by the cover crop.

In this year, extreme maximum temperatures above 40º C occurred between August 4th and 6th associated with the recognised susceptibility of 'Fernão Pires' to hot and dry conditions (Castro and Lopes, 1990) caused high levels of sunburn injuries in leaves and clusters. Great differences in sunburn injuries were found between the two soil management techniques, once the NGC presented 40.7% and 34.6% of sunburn leaves and clusters, respectively, against 31.1% and 19.9% observed on the tilled soil. The higher canopy density (LLN) and the minor sunlight interception resulting from the highest vigour (laterals leaf area) observed on the tilled soil seems to be the major cause for these discrepancies.

TABLE IV

Influence of soil management on canopy structure and microclimate during the ripening in 2005.

Influência da manutenção do solo na estrutura e no microclima do coberto durante a maturação em 2005.

Year	Treatment	LLN	PAR at clusters level	% sunburn leaves	% sunburn clusters
2005	NGC	2.17	599.6	40.7	34.6
	TIL	2.64	267.7	31.1	19.9
	Sig.	*	***	***	***

Sig. – Significance level; n.s. – non significant at 5% level by F test; significant at 5% (*), 1% (**) and 0.1% (***) by F test. NCG – Natural Grass Cover; TIL – Tillage; PAR – Photosynthetic active radiation (µmol.m^{-2}.s^{-1}).

Agronomic results

Yield components in the two years of the trial are presented in Table V. The ANOVA results related to 2004 show significant differences in berry and cluster weight and in the bunch rot intensity. In fact, the introduction of soil tillage induces higher berry and cluster weight. In Portugal similar results for cluster weight were observed by Afonso *et al.* (2003) with the white variety 'Alvarinho', but differences among berry weight were not found. Tesic *et al*. (2007) have also found lower berry weight in cover cropped vineyard.

The rainfall that occurred during the second half of August (32.7 mm) was the major factor for bunch rot intensity in both treatments, with 42.1% and 50.4% for NGC and TIL, respectively. The differences can

TABLE V

Influence of soil management on yield, exposable surface area and on their relation, in 2004 and 2005.

Influência da manutenção do solo no rendimento, superfície foliar exposta e sua relação, em 2004 e 2005.

Year	Treatment	Berry weight (g)	Clusters/Vine	Fertility Index	Cluster weight (g)	Yield (t/ha)	Bunch rot intensity (%)
2004	NGC	1.86	23.5	-	135.7	10.2	42.1
	TIL	2.30	23.0	-	149.1	10.8	50.4
	Sig	**	*n.s.*		*	*n.s.*	*
2005	NGC	1.54	18.2	1.05	111.9	6.6	4.8
	TIL	1.77	21.4	1.25	184.4	12.3	5.0
	Sig	**	***	***	***	***	*n.s.*

Sig. – Significance level; n.s. – non significant at 5% level by F test; significant at 5% (*), 1% (**) and 0,1% (***) by F test. NCG – Natural Grass Cover; TIL – Tillage.

be justified by the vigour increase promoted by the soil tillage, expressed by lateral leaf area of the vines (Fig. 5) and by the shoots weight (Table VI) that lead to a denser canopy. The long-term soil cover crop induced a decrease of canopy density and improves the fruit zone microclimate, conducing to a decrease of bunch rot incidence as observed by Morlat and Geoffrion (2000).

TABLE VI

Influence of soil management on vigour and vegetative growth.

Influência da manutenção do solo no vigor e expressão vegetativa.

Year	Treatment	Shoots/vine	Pruning weight (kg/vine)	Shoots/m	Shoot weight (g)	Ravaz Index
2004	NGC	18.1	0.60	14.5	34.3	5.3
	TIL	17.8	0.83	14.3	47.5	4.1
	Sig	*n s*	***	*n s*	***	*ns*
2005	NGC	14.5	0.59	11.6	41.0	3.7
	TIL	16.3	0.96	13.0	61.2	4.5
	Sig	***	***	***	***	**

Sig. – Significance level; n.s. – non significant at 5% level by F test; significant at 1%(**) and 0,1%(***) by F test. NCG – Natural Grass Cover; TIL – Tillage.

In 2005, differences in all the yield parameters were observed between the two soil management strategies. The highest number of clusters on tilled soil was due to higher fertility index, probably due to a better N nutrition and higher shoot weight in 2004. The huge differences between tilled soil and cover cropped soil were verified in the cluster weight and total yield per hectare. The soil tillage leads to an increase of 65% and 86% in cluster weight and yield per hectare, respectively. The sunburn injury of the clusters (Table IV) was one of the main factors for these results.

The soil tillage induced an increase in most of the variables related to vigour and vegetative growth (Table VI). Indeed, other authors (Le Goff-Guillou *et al*, 2000; Morlat and Geoffrion, 2000) have found similar results, namely a marked decrease of the vegetative growth and vigour with cover crop. In 2004, differences were observed in total pruning and shoot weight, in spite of the non significant effect on the Ravaz index.

In 2005, the dry and hot climatic conditions lead to higher differences in pruning weight, shoot number and weight. The Ravaz index was significantly reduced due to the significant loss of yield by sunburn injuries on cover cropped soil. An unexpected increase in shoot weight was observed from 2004 to 2005 (a hotter and driest year).

The effects of vineyard soil management on yield and vigour are dependent of the year and are more pronounced in the hot and dry years, as was also noticed by Tesic *et al*. (2007) and Le Goff-Guillou *et al.* (2000).

Must composition

The analysis of must composition, presented on Table VII, shows that, in 2005, the lower soil water content and photosynthetic rates decreased the must sugar content and the higher temperatures in this year conduced to lower must acidity.

Soil tillage induced a slight increase of probable alcoholic content (PAC) in 2005 and, in 2004, the same tendency was observed, although with no statistical significance. These results are different from those observed by Howell *et al.* (2007), Monteiro and Lopes

TABLE VII

Influence of basal leaf removal and soil management on must composition, in 2004 and 2005.

Influência da desfolha da manutenção do solo na composição do mosto, em 2004 e 2005.

Year	Treatment	Prob. Alc. Content (%v/v)	Titratable Ac. (g/l ac. Tart)	pH	Tartaric Ac. (g/l)	Malic Ac. (g/l)
2004	**NGC**	12.9	6.85	3.24	3.10	1.95
	TIL	13.1	7.00	3.26	2.80	2.35
	Sig.	*n.s.*	*n.s.*	*n.s.*	***	*
2005	**NGC**	10.7	5.75	3.11	3.97	1.65
	TIL	11.1	5.76	3.16	3.81	2.08
	Sig.	**	*n.s.*	***	*n.s.*	***

Sig. – Significance level; n.s. – non significant at 5% level by F test; significant at 5% (*), 1% (**) and 0,1% (***) by F test. NCG – Natural Grass Cover; TIL – Tillage

(2007) and Xi *et al.* (2011) and derive, probably, from the differences in photosynthetic rates registered in this treatment in both years that was even more expressive in 2005.

Titratable acidity and pH were not significantly affected by the soil management, which are different from the results obtained by Monteiro and Lopes (2007) and Xi *et al.* (2011), except for the pH in 2005 that had a slight increase with soil tillage treatment (but without oenological relevance). The concentrations of the two most important acids of the must were changed according to the soil management: a decrease in tartaric acid and an increase in malic acid were verified in tilled soil. This relationship can be relevant since it can promote more balanced and fresh wines.

CONCLUSIONS

In spite of the beneficial effects of cover crops, its use in vineyards is still controversial mainly due to their competition with the vines. In this study, developed in a vineyard with a long term natural cover crop, tillage application induced an increase in vine vigour and yield, as well as a better nutritional grapevine status, higher photosynthetic rate and better must quality.

The effects of tillage can be ascribed to a better soil water availability, to the decrease of nutritional competition and to the higher soil organic matter mineralisation, which was quickly enough to improve nitrogen levels in the first year and to promote better magnesium nutrition in the second year. This allowed a higher photosynthetic activity when compared with the natural cover crop treatment. The remarkable responses of vegetative growth and yield to tillage treatment contributed to differences in the canopy structure, berry and cluster weight and must composition.

It is important to emphasize that the meteorological conditions occurred in the two years of experiment were atypical. Both years were characterize by a dry spring, but the rainy events occurred in the summer of the first year caused high bunch rot levels, which were more pronounced in the tilled treatment. On the other hand, a heat wave occurred in the second year causing yield losses much higher in the cover crop treatment.

Therefore, soil management strategies should be appropriate to the climatic conditions of the year. This issue should be taken into account in the future face to climate change scenarios expected for Iberian Peninsula and in other Mediterranean climates. In fact, since the future climate scenarios point to an increasing number of years similar to 2005 or even more severe (heat waves, heavy rainfall concentrated in winter and prolonged drought), the soil tillage in spring on a non-irrigated viticulture can be a strategic tool to mitigate these stress conditions.

ACKNOWLEDGEMENTS

The present study was funded by the “Plano de Acção para a Vitivinicultura Bairradina”, supported by the “Direcção Regional de Agricultura da Beira Litoral” and by the “Comissão Vitivinícola da Bairrada”. We also acknowledge Sogrape Vinhos, S.A. and all the students that contributed to the data collection.

REFERENCES

Afonso J.M., Monteiro A., Lopes C.M., Lourenço J., 2003. Enrelvamento do solo em vinha na região dos Vinhos Verdes. Três anos de estudo na casta ‘Alvarinho’. *Ciência Téc. Vitiv.*, **18**, 47-63.

Amaro P., Raposo M.E., 2001. *Relatório final do campo de demonstração de protecção integrada da vinha da região vitivinícola de Palmela (1996-2000).* Instituto Superior de Agronomia/S.A.P.I., 25pp.

Amaro P., Ribeiro J.A., Ramadas I., 2001. *Infestantes*. In A Protecção Integrada da Vinha na Região Norte. Pedro Amaro (eds.). Edição ISA/PRESS, Lisboa, 68-81.

Barbeau G., Riou C., Clémént C., Cornillet A., Marsault J., 1999. Modifications du micro-climat thermique et radiatif de la vigne par l'enherbement dans trios terroirs du Val de Loire: influence sur la composition des vendanges de Cabernet Franc. *11th Meeting, GESCO*, Sicily, pp. 880-884.

Battany M.C., Grismer M.E., 2000. Rainfall runoff and erosion in Napa Valley vineyards: effects of slope, cover and surface roughness. *Hydro. Proc.*, **14**, 1289-1304.

Baumgartner K., Steenwerth K.L., Veilleux L., 2008. Cover-crop systems affect weed communities in a California vineyard. *Weed Science*, **56**(4), 596-605.

Beuret E., Neury G., 1987. Désherbage et entretien du sol en viticulture. *Rev. Suisse Vitic. Arboric. Hortic.*, **19**(1), 48-52.

Cameira M.R., Fernando R.M., Pereira L.S., 2003. Soil macropore dynamics affected by tillage and irrigation for a silty loam alluvial soil in southern Portugal. *Soil & Tillage Research*, **70**, 131-140.

Carbonneau A., 2001. Gestion de l'eau dans le vignoble: Théorie et pratique. In: *12èmes Journées GESCO, Journée professionnelle: "Gestion de l'eau dans le vignoble*". AGRO Montpellier, Montpellier, pp. 3-21.

Cardoso J.C., 1974. A classificação dos solos de Portugal. *Boletim de Solos*, **17**, 14-46.

Castro R., Almeida C., Cruz A., Frade P., Ribeiro F., Aires A., 1999. Cepage 'Baga' – Region Bairrada. De la conduite traditionelle jusqu'au systeme 'LYS'. *11émes Journées GESCO*, Sicile, pp. 689-694.

Castro R., Lopes C., 1990. Influência do sistema de poda e de condução da vegetação sobre a fertilidade e produção na casta Fernão Pires. In: *I Congresso Ibérico de Ciências Hortícolas*, Actas de Horticultura. Vol. IV. Lisboa. 314-319.

Cavaco M., Calouro F., Clímaco P., 2005. *Produção integrada da cultura da vinha*. Direcção-Geral de Protecção das Culturas, 146p.

Celette F., 2007. *Dynamique des fonctionnements hydrique et azoté au sein d'une vigne enherbée sous le climat méditerranéen*. Ph.D. Thesis, SupAgro, Montpellier, 200 pp.

Celette F., Findeling A., Gary C., 2009. Competition for nitrogen in an unfertilized intercropping system: The case of an association of grapevine and grass cover in a Mediterranean climate. *Europ. J. Agronomy*, **30**, 41-51.

Celette F., Gaudin R., Gary C., 2008.Spatial and temporal changes to the water regime of a Mediterranean vineyard due to the adoption of cover cropping. *Europ. J. Agronomy*, **29**, 153-162.

Chantelot E., Carsoulle J., Legoff I., 2001. Maitrise de la teneur en azote des moûts en système enherbement permanent par pulvérisation foliaire d´azote. GESCO. *Compte Rendu*, **16**, 465-472.

Chaumont M., Osório M.L, Chaves M.M, Vanacker H., Morot-Gaudry J.-F., Foyer C.H., 1997. The absence of photoinhibition during the mid-morning depression of photosynthesis in *Vitis vinifera* grown in semi-arid and temperate climates. *J. Plant Physiol.*, **150**(6), 743-751.

Curtin D., Beare H.M., Fraser P.M., Gillespie R., Harrison-Kirk T., 2010. Soil organic matter loss following land use change from long-term pasture to arable cropping: Pool size changes and effects on some biological and chemical functions. In: *19th World Congress of Soil Science, Soil Solutions for a Changing World*, Brisbane (Australia). pp 213-216.

Dabney S.M., Delgado J.A., Reeves D.W., 2001. Using winter cover crops to improve soil andwater quality. *Commun. Soil Sci. Plant Anal.*, **32**(7&8), 1221-1250.

Deloire A, Carbonneau A., Federspiel B., Ojeda H., Wang Z., Costanze P., 2003. La vigne et l'eau. *Progrés Agricole et Viticole*, **120** (4), 79-90.

Eiras-Dias J., Faustino R., Clímaco P., Fernandes P., Cruz A., Cunha J., Veloso M., Castro R., 2011. *Catálogo das castas para vinho cultivadas em Portugal*. 1º Volume, 109 pp.

Gago P., Cabaleiro C., Garcia J., 2007. Preliminary study of the effect of soil management systems on the adventitious flora of a vineyard in northwestern Spain. *Crop Protection*, **26**, 584-591.

Geoffrion R. ,1999. L´enherbement permanent, 40 ans après. *Phytoma*, **519**, 25-27.

Hartwig N.L., Ammon H.V., 2002. Cover crops and living mulches. *Weed science*, **50**(6), 688-699.

Hirschfelt D.J., 1998. Soil fertility and vine nutrition. *In*: *Cover Cropping in Vineyards. A Grower's Handbook.* 61-68. Ingels C.A., Bugg R.L., McGourty G.T., Christensen L.P. (eds.), University of California. Publication 3338. Oakland. USA.

Howell C.L., Lanyon D.M., McCarthy M., 2007. Effect of vineyard traffic and soil management practices on berry growth, grape juice parameters and yield of Shiraz in the Barossa Valley (poster). In: *13th Australian Wine Industry Technical Conference*, Adelaide.

Keller M., 1997. Can Soil management replace nitrogen fertilisation? - A European perspective. *The Australian Grapegrower & Winemaker*. **408**, 23-28

King A.P., Berry A.M., 2005. Vineyard $\delta^{15}N$, nitrogen and water status in perennial clover and bunch grass cover crop systems of California's central valley. *Agriculture, Ecosystems and Environment*, **109**, 262-272.

Kottek M., Grieser J., Beck C., Rudolf R., Rubel F., 2006. World map of the Köppen-Geiger climate classification updated. *Meteorologische Zeitschrift*, **15**(3), 259-263.

Le Goff-Guillou I., Marsault J., Riou C., 2000. Impacts de l`enherbement sur le fonctionnement de la vigne, la composition des moûts, les durées de fermentation et la qualité des vins. *Progrès Agricole et Viticole*, **5**, 103-110.

Lopes C.M.A., 1999. Relationships between leaf water potential and photosynthetic activity of field-grown grapevines under a Mediterranean environment. *Acta Hort.*, **493**, 287-292.

Lopes C., Monteiro A., Rückert F.E., Gruber B., Steinberg B., Schultz H.R., 2004.Transpiration of grapevines and co-habitating cover crop and weed species in a vineyard. A "snapshot" at diurnal trends. *Vitis*, **43**, 111-117.

Lopes C.M., Pinto P.A., 2005. Easy and accurate estimation of grapevine leaf area with simple mathematical models. *Vitis*, **44**(2), 55-61.

Maigre D., Aerny J., 2000. Essai d'enherbement et de fumure azotée sur Gamay dans le bassin lémanique – 1. Résultats agronomiques. *Revue Suisse Vitic. Arboric. Hortic.*, **32**(3), 145-151.

Monteiro A., Lopes C.M., 2007. Influence of cover crop on water use and performance of vineyard in Mediterranean Portugal. *Agriculture, Ecosystems and Environment*, **121**, 336-342.

Morlat R. 2001. L'enherbement permanent contrôlé des sols viticoles. *Phytoma*. **530**: 28-31.

Morlat R., Geoffrion R., 2000. L´enherbement permanent contrôlé des sols viticoles. Vint ans de recherches sur le terrain en Anjou. *Phytoma*, **530**, 28-31.

Morlat R., Jacquet A., 1993. The soil effects on the grapevine root system in several vineyards of the Loire Valley (France). *Vitis*, **32**, 35-42.

Ojeda H., 2001. Bases ecophysiologiques et choix techniques dans la gestion de l'eau dans les vignobles d'Argentine. *GESCO XI* *journées du groupe d'étude des systèmes de conduite de la vigne*, Montpellier, France, **1**, 75-86.

Olmstead M.A., Wample R.L., Greene S.L., Tarara J.M., 2001. Evaluation of potential cover crops for inland Pacific Northwest vineyards. *Am. J. Enol. Vitic.*, **52**, 292-303.

Ovalle C., Pozo A., Peoples M.B., Lavín A., 2010. Estimating the contribution of nitrogen from legume cover crops to the nitrogen nutrition of grapevines using a 15N dilution technique. *Plant Soil*, **334**, 247-259.

Petrie P.R., Trought M.C.T., Howell G.S., 2000. Influence of leaf ageing, leaf area and crop load on photosynthesis, stomatal conductance and senescence of grapevine (Vitis vinifera L. cv. Pinot noir) leaves. *Vitis*, **39**(1), 31-36.

Quelhas-dos-Santos J., 1996. *Fertilização. Fundamentos da utilização dos adubos e correctivos*. Publicações Europa-América (ed.).Lisboa, 441pp.

Riou C., Payan J.C., 2001. Outils de gestion de l'eau en vignoble méditerranéen. Application du bilan hydrique au diagnostique du stress hydrique de la vigne. In: *12èmes Journées GESCO, Journée professionnelle: «Gestion de l'eau dans le vignoble»*, AGRO Montpellier, Montpellier, pp. 125-133.

Rodriguez-Lovelle B., Soyer J., Molot C., 2000. Nitrogen availability in vineyard soils according to soil management practices. Effects on vine. *Acta Hort.*, **526**, 277-286.

Ruiz-Colmenero M., Bienes R., Marques M.J., 2011. Soil and water conservation dilemmas associated with the use of green cover in steep vineyards. *Soil and Tillage Research*, **117**, 211-223.

Sainju U.M., Singh B.P., Whitehead W.F., 1998. Cover crop root distribution and its effects on soil nitrogen cycling. *Agron. J.*, **90**, 511-518.

Scholander P.F., Hammel H.T., Bradstreet E.D., Hemmingser E.A., 1965. Sap pressure in vascular plants: negative hydrostatic pressure can be measured in plants. *Science*, **148**, 339-346.

Smart R.E., Robinson M., 1991. *Sunlight into wine. A Handbook for winegrape canopy management*. Winetitles, Adelaide, 88 pp.
Steenwerth K., Belina K.M., 2008. Cover crops enhance soil organic matter, carbon dynamics and microbiological function in a vineyard agroecosystem. *Applied Soil Ecology*, **40**, 359-369.

Tesic D., Keller M., Hutton R., 2007. Influence of vineyard floor management practices on grapevine vegetative growth, yield, and fruit composition. *American Journal of Enology and Viticulture*, **58**(1), 1-11.

Tournebize J., 2001. *Impact de l'enherbement du vignoble alsacien sur le transfert des nitrates*. Ph.D. Thesis, Université Louis Pasteur, Strasbourg, 306 pp.

Xi Z-M., Tao Y-S., Zhang L., Li H., 2011. Impact of cover crops in vineyard on the aroma compounds of *Vitis vinifera* L. cv Cabernet Sauvignon wine. *Food Chemistry*, **127**, 516-522.

Zuffery V., Murisier F. Schultz H.R., 2000. A model analysis of the photosynthetic response of *Vitis vinifera* L. cvs Riesling and Chasselas leaves in the field: I. Interaction of age, light and temperature. *Vitis*, **39**(1), 19-26.