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

Amândio Cruz1*, Manuel Botelho1, José Silvestre2 and Rogério de Castro1

1 Instituto Superior de Agronomia, Tapada da Ajuda, 1349-017 Lisboa, Portugal, e-mail: rcastro@isa.utl.pt
2 INIA V, I.P., INIA - Dois Portos, Quinta da Almoínha, 2565-191 Dois Portos, Portugal, e-mail: josesilvestre@inrb.pt
*corresponding author: Amândio Cruz. Instituto Superior de Agronomia, Tapada da Ajuda, 1349-017 Lisboa, Portugal, Tel.; 213653100, e-mail: rcastro@isa.utl.pt

(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 enrolvados e mobilizados. O estado nutritivo da vinha foi também melhorado pela realização da mobilização do solo e, como consequência, verificaram-se taxas fotorarentes 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 (40°25’41”N, 8°30’05”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 1, 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\(_2\)O = 7) at the 0-20 cm level and moderately acid at 20-50 cm (pH H\(_2\)O = 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 (glyphosate, 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
The dominant species in the data collection is Holcus lanatus L. This graminaceous 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,
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 known phenomenon and was verified in vines in Mediterranean climates (Celette et al., 2009).

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 (Ψpd). 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 Ψpd is presented in Figure 2 for the period between bloom and harvest in both

### 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.

<table>
<thead>
<tr>
<th>Year</th>
<th>Soil management</th>
<th>N</th>
<th>P</th>
<th>K</th>
<th>Ca</th>
<th>Mg</th>
<th>K/Mg</th>
</tr>
</thead>
<tbody>
<tr>
<td>2004</td>
<td>NGC</td>
<td>7.3</td>
<td>2.6</td>
<td>31.4</td>
<td>24.3</td>
<td>3.0</td>
<td>10.7</td>
</tr>
<tr>
<td></td>
<td>TIL</td>
<td>10.1</td>
<td>2.8</td>
<td>30.5</td>
<td>31.1</td>
<td>3.1</td>
<td>10.0</td>
</tr>
<tr>
<td></td>
<td>Sig</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>n.s.</td>
</tr>
<tr>
<td>2005</td>
<td>NGC</td>
<td>8.1</td>
<td>3.0</td>
<td>41.0</td>
<td>27.4</td>
<td>2.4</td>
<td>18.0</td>
</tr>
<tr>
<td></td>
<td>TIL</td>
<td>8.1</td>
<td>2.4</td>
<td>31.5</td>
<td>27.1</td>
<td>3.5</td>
<td>10.7</td>
</tr>
<tr>
<td></td>
<td>Sig</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>n.s.</td>
</tr>
</tbody>
</table>

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.
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.

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 \( \Psi_{pd} \) never reached values of severe water stress, \( \Psi_{pd} \) decreased from the middle of June to the end of July, and no water stress was verified at 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**


<table>
<thead>
<tr>
<th>Soil management</th>
<th>mg/100 g of grapes</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N</td>
</tr>
<tr>
<td>NGC</td>
<td>122.2</td>
</tr>
<tr>
<td>TIL</td>
<td>120.7</td>
</tr>
</tbody>
</table>

NGC – 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 \( \Psi_{pd} \) never reached values of severe water stress, \( \Psi_{pd} \) decreased from the middle of June to the end of July, and no water stress was verified at the end of the maturation period due to the rainfall occurred in August (about 50 mm).

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


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 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 (Cellote 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 influence 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...
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 $\Psi_{pd}$ evolution. Moreover, different trends for leaf water potential were found (Figure 4). At July 12th, the minimum $\Psi$ ($\Psi_{min}$) occurred in the tillage treatment at solar noon. However, for August 2nd, $\Psi_{min}$ 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.

The small differences in $\Psi_{pd}$ 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 m² of leaf area per vine in 2004 and 2.32 m² in 2005). In 2004 this increase was essentially due to the secondary leaf area (plus 1.89 m² of lateral leaf area per vine). In 2005 the principal leaf area have also contributed for it (plus 0.51 m² of principal leaf area per vine), although the major role played by the lateral leaf area (plus 1.81 m² of lateral leaf area per vine). Maigre and Aerny (2000) have also observed that lateral leaf area played a main
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 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.

**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 IV**

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

<table>
<thead>
<tr>
<th>Year</th>
<th>Treatment</th>
<th>LLN</th>
<th>PAR at clusters level</th>
<th>% sunburn leaves</th>
<th>% sunburn clusters</th>
</tr>
</thead>
<tbody>
<tr>
<td>2005</td>
<td>NGC</td>
<td>2.17</td>
<td>599.6</td>
<td>40.7</td>
<td>34.6</td>
</tr>
<tr>
<td></td>
<td>TIL</td>
<td>2.64</td>
<td>267.7</td>
<td>31.1</td>
<td>19.9</td>
</tr>
</tbody>
</table>

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

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).

**TABLE V**

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

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.

**TABLE VI**

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

Sig. – Significance level; n.s. – non significant at 5% level by F test; significant at 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**


