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Extreme viticulture:
from a cultural landscape to an economic and environmental sustainability

11-14 May 2022, Vila Real (UTAD)

Book of Proceedings

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Electrical Resistivity Tomography for soil moisture estimation in terraced vineyards: a case study in the Douro Region, Portugal

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Keywords:terraced vineyard, Electrical Resistivity Tomography

Abstract. The Douro Region (Portugal), with an extension of ca. 43 000 ha of vineyards, is one of the most important wine regions in Europe and listed as a World Heritage site (UNESCO 2001). This is a supplementary reason for actions to preserve its natural resources such as soil and water. The regional topography exposes soils to severe erosion risk. In order to mitigate these risks, vineyards are installed in conservation structures typical of this area, called Terraços or Socalcos (Terraces). These structures require important earth movement to secure them properly which results in strong disturbance of soil structure and soil water movement. The aim of this study is to compare soil water content of a terraced vineyard in the wet season (January) with that in the dry season (July), using Electrical Resistivity Tomography (ERT). ERT has been broadly used to assess soil water moisture, also in vineyards. However, in this case it is necessary to take into account the complex topography of the terraces in order to obtain a reliable soil profile model. The study was carried out in a terraced vineyard at Peso da Régua. ERT transects were measured in three neighbouring areas of the vineyard: Terrace, Inter-terrace and Terrace. Transects in the Terrace areas were parallel to the slope while transects in the Inter-terrace area were perpendicular to the slope. Six transects were carried out (three in January and three in July in the same positions). Electrode spacing along the 20 m transects was 0.5 m. Also, soil samples were taken at 4 depths (0.0 - 0.5 m; 0.5 - 0.10 m; 0.10 - 0.20 m; >0.20 m) for gravimetric water content determination. ERT data obtained were inverted taking into account the topography, to obtain soil electrical resistivity profiles. For this case study, ERT results provided an adequate representation of soil moisture profiles, offering possibilities of fast and detailed appraisal of soil water content and distribution in terraced vineyards.

Introduction

The Douro Region covers 250000 ha, of which 46000 ha are vineyards, producing several wine types including the Port, which is mainly exported (near 1 million liters annually in the last decade), with a very significant contribution to the Portuguese wine production, the wine export and the Gross Agricultural Product (Damásio et al., 2010. This Region Region became UNESCO World Heritage (UNESCO World Heritage Site 2001), a status that fostered socio-economic and cultural activities in the region but it also highly increases responsibilities in terms of conservation and sustainable use of regional resources, as it is the case of soil and water. The high potential erosion risk prevailing in such topographic conditions has been tackled for long time with traditional soil conservation structures, namely dry-stone walled terraces, which depended on the availability of cheap labor for constructing and maintaining those structures. The old terraces were supported by vertical stone walls that have been replaced by *patamares,* benches of land with slopes of 100 - 175%. This change responds to the need of adapt new technologies to the automation of the vineyard (Fernandes et al, 2017). The construction of embankments and risers to support the terraces cause alterations both in the internal structure of the soil and in the circulation of water, which may lead to raise a set of problems related to soil hydrological processes (Fernandez et al, 2017).

The aim of this study is to compare soil water content of a terraced vineyard in the wet season (January) to that same vineyard in the dry season (July), using Electrical Resistivity Tomography (ERT). ERT has been broadly used to assess soil water content (SWC) in many soil types, including vineyard soils (Beff et al., 2013; Samouëlian et al., 2005). Friedman (2005) considers that soil properties affecting electrical resistivity (ER) are: water content, porosity, CEC, temperature…Many authors have used this geophisical method in soil vineyards (Courjault-Rade et al., 2010; Dafonte et al., 2013, Brillante et al., 2015). Dafonte et al. 2013 concluded that this method is useful to evaluate water distribution in soil.

However, in this case, it is necessary to take into account the complex topography of the terrace in order to obtain a reliable soil profile model due to the fact that, in this uneven terrain, the topography effects may lead to misleading anomalies (Fox et al., 1980). Therefore, it is important to assess the topographical effect, trying to erase it for a better understanding of the (ER) soil profile. The method to avoid the topographical influence is to incorporate the topography as a variable to calculate ER (Lu et al. 2015).

Methods and sources

The study was carried out in the Douro Region in the Vinícola Quinta do Vallado´s terraced vineyards (41º 09,5 N, 7º 45,9 O) in Peso da Régua, (Portugal), Figure1.

Figure 1. Location site

In order to assess soil water content status using ERT, ERT transects were measured in three neighboring areas of the vineyard: Terrace, Inter-terrace and Terrace. Transects in the Terrace areas were parallel to the slope while transects in the Inter-terrace area were perpendicular to the slope. Six transects were carried out (three in January and three in July, in the same positions). Electrode spacing along the 20 m transects was 0.5 m (Figure 2). ERT survey was carried out using a Terrameter SAS 1000 device (ABEM) using the Wenner array for the measurements, because it is the appropriate to detect RE variations in horizontal structures (Loke, 2011; Samouëlian et al., 2005). The data obtained during ERT field measurements presented a classical pattern of apparent resistivity pseudo-sections. The resistivity data obtained from the field were then inverted using RES2DINV 3.59 software (Loke 2010), which is based on the regularized least-squares optimization method (Loke and Barker 1996). The apparent resistivity data from the 2D survey were inverted using a least-square method to obtain a pseudo-resistivity 2D- including topographic variations, with a finite-element method that incorporates the topography into the modelling mesh used. The type of topography modelling used was distorted with a finite-element grid with damped distortion. The soil resistivity profile expected in this type of terraces presents high water content in the toe of the slope. Soil samples were taken at 4 depths (0.0 - 0.5 m; 0.5 - 0.10 m; 0.10 - 0.20 m; >0.20 m) for gravimetric water content determination, Figure 2. Soil moisture was assessed gravimetrically (oven-dry soil at 105º C for 48 h), bulk density being determined with the oven-dry soil mass and the cylinder volume. Porosity was calculated assuming $2.65 \cdot 10^3$ kg•m^{-3} as particle density. Oven-dried samples were sieved (2 mm) and coarse fragments mass determined.

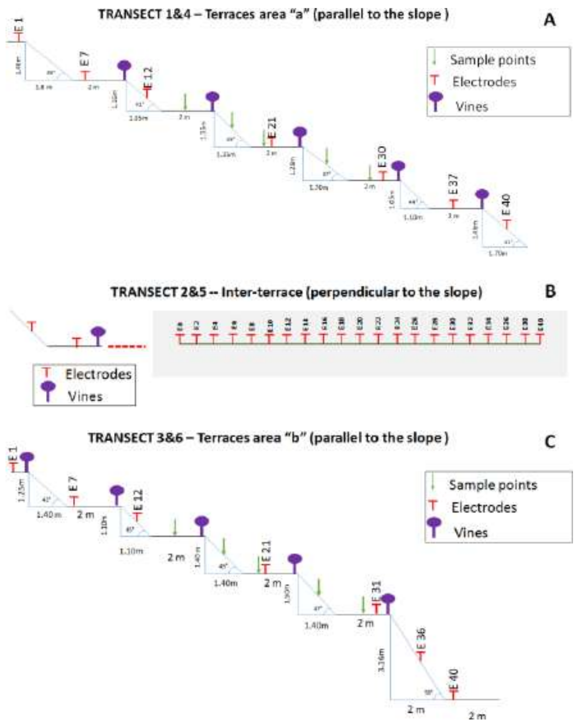

Figure 2. Sampling Scheme.

Results

Figure 3 shows, for the transects parallel to the slope, SWC in the different sub-areas of the terrace (upper bench, upper riser, etc.) in winter and summer (1-2 and

3-6). As expected, SWC is higher in winter than in summer for all sub-areas and depths; and these differences are more evident in the first 5 cm of the soil (28% - 12% upper bench, 15%-9% upper riser, 19%-9% intermediate bench, 16-9% lower riser and 17%-11 % lowerbench). On the other hand, at 5-10 cm, 10-20 cm and >20 cm these differences between winter and summer are less appreciable.

In January, soil samples taken below 5 cm presented lower SWC values as it would be expected for a humid winter condition, hence soil was far from saturation and the subsurface and underground flows were slow.The values (all depths) ranged from 28% to 12%. Moreover, it was observed that the risers at >5 cm depth had a higher SWC than the adjoining benches. The decrease of SWC by depth suggested that the soil, despite the fact that the winter season was already advanced, was not wet from the surface, nor it was able to be wetted from deeper areas by underground flows. SWC decrease was also observed between the upper and lower bench, which may imply a slow water flow and preferably vertical flow (not parallel to the slope). This may explain the reduction of SWC by depth and along the risers.

In the summer sampling, SWC was lower than in winter, as expected, presenting the terraces a great uniformity by depth and by the position on the slope. Therefore, the range of values for all depths was tighter than in winter (13% to 8%). However, SWC distribution was different from winter; with higher SWC values in some of the deeper areas of the soil profile (e.g., intermediate bench- 10-20cm; >20 cm).

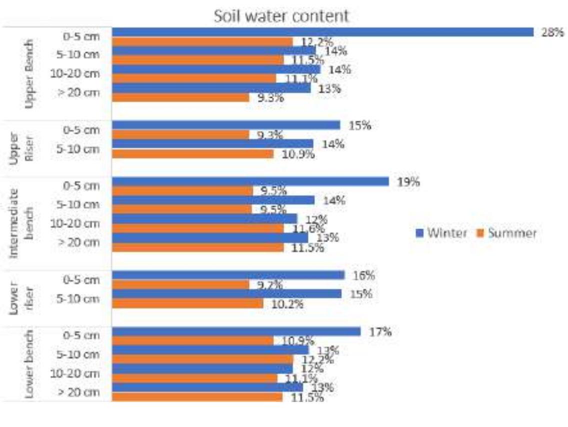

Figure 3. Soil water content in difference locations of the terraces (upper bench, upper riser, intermediate bench, lower riser and lower bench).

In the Figure 4 the ERT inverted profiles of winter and summer transects are shown. The ER differences in the winter transects between the top soil (0.05 cm) and the rest of the depths can be noticed, meanwhile the ER summer transects showed more uniformity. Due to the fact that the transects were performed in the same locations in January and July, similar ER can be appreciated. There were areas of high resistivity in the same locations that may be rests of the materials used in the construction of the terraces. The distribution of the ER in winter and summer seemed to be similar (except for the top soil, as mentioned above) because ER measurements are not only affected by SWC but also by other factors such as soil physical and chemical properties, soil structure, etc.

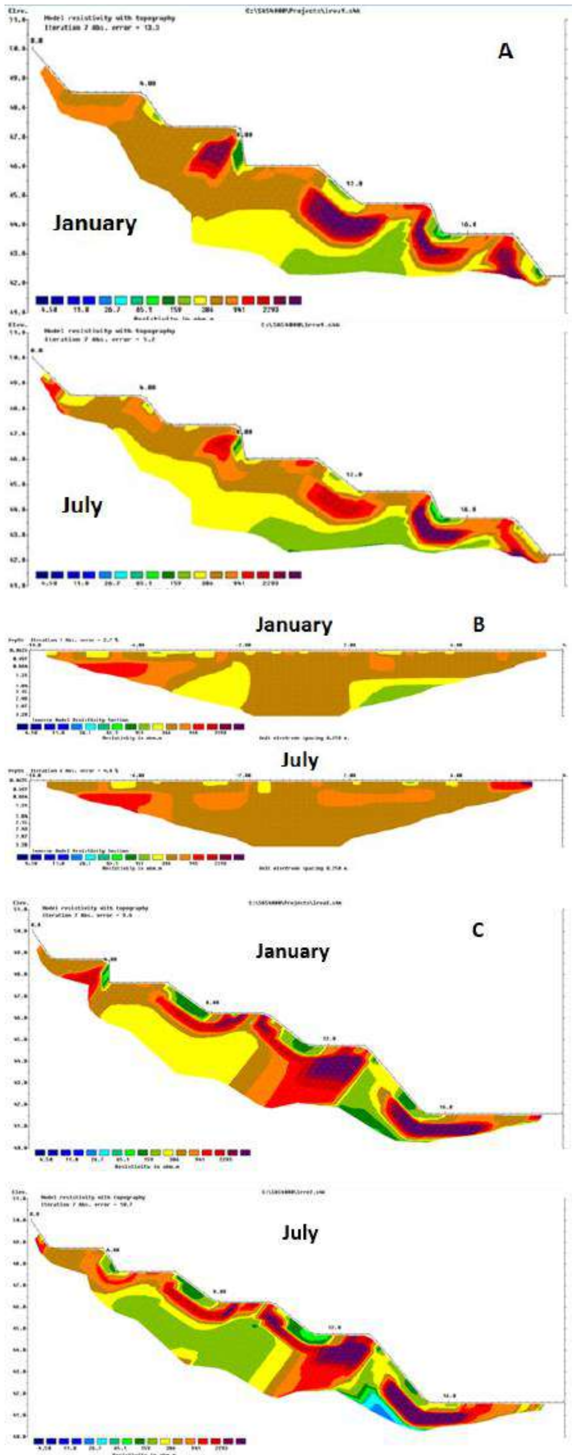

Figure 4. Electrical Resistivity profiles in the transects (using inverted RES2DINV), Terraced area (A), Inter-Terraced area (B) and Terraced area (C) in January and July.

In winter, it can be observed that the risers had higher SWC values than the contiguous benches, which is consistent with the soil sampling. The high slope of the vineyard and the lack of vegetation along it caused a very low infiltration rates in these areas, explaining the high uniformity of the SWC by depth in the benches. SWC reduction or increase were not obvious when comparing the upper and lower points of the transects, both on the benches and on the risers, in winter and in summer.

In summary, ERT measurements/soil inverted profiles were useful to appreciate the reduction of SWC along the terrace and by depth in both seasons, although ERT measurements are easier to understand when there are severe changes in ER (dry areas, rocks, etc) than when the ER is uniform.

Conclusions

ERT inverted profiles obtained taking into account the topographic variable were useful to obtain more reliable/realistic soil map profiles of the terraces, and they can be helpful to understand the distribution of SWC. Likewise, similar (ER) patterns can be observed between winter and summer, with high resistivity areas which can be rests of the construction materials used to build the terraces.

The general state of SWC in summer and especially in winter (lower than expected for that time) suggested that the predominant flows are slow and preferably vertical and not parallel to the slope. That may explain the reduction of humidity in depth and along the slope.

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