SUSTAINABLITY OF VINEYARDS IN THE PRIORAT REGION (NE SPAIN)

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ABSTRACT
The Priorat region (NE Spain), where vineyards have been cultivated in hillslopes since the XII century, has undergone significant changes since the beginning of the 1990s. New market opportunities and EU Common Agricultural Policies have been accelerating land use and landscape changes. New farming systems based on the construction of linked bench terraces are implemented, being old vineyards and abandoned agricultural fields transformed into new vineyards fields. However, land terracing is affecting soil physical properties, with a negative impact in water intake and storage into the soil. In addition some of the new terraces, constructed without a suitable design, suffer land slides and further collapse. The analysis carried out comparing the new and the old vineyards make to think about the sustainability of the new system in the long term, with repercussions in grape quality.

KEYWORD
Land terracing - sloping terrain - soil properties- vineyard – grape quality

INTRODUCTION

Agriculture in the Mediterranean environment has undergone significant changes since the introduction of mechanisation in the 1950s. The consequences of it have been the intensification of agriculture and in some cases the abandonment of crops in traditional agricultural areas, particularly in mountain environments traditionally devoted to subsistence farming (Caraveli, 2000). The intensification of agriculture in mountain environments requires land levelling and terracing operations (Borselli et al., 2006). This reduces some of the morphology limitations of hillslopes for agriculture and reduces labour, but it causes irreversible changes in soil properties and soil hydrology of still unknown consequences.

Vines are one of the crops that more suffered these impacts in some areas during the last two decades. These changes have coincided in time with the implementation of conversion and restructuring policies, which encourage accelerated land use changes, replacing traditional low-intensity production systems by farming systems based on high technology and mechanisation. Some negative consequences of these transformations have been reported: e.g. the irregularity of soil depth and alteration of natural drainage and soil hydrological properties (Ramos et al., 2007). The fragility of the system and the system sustainability could be seriously affected.

The Priorat region (Catalonia, NE Spain) is a clear example of these mountain areas, which has suffered significant changes during the last two decades. This is a traditional area for wine production where vineyards have been cultivated in hillslopes with small stone wall terraces. However, from the late 1980s there is a boom of viticulture, based on a new terracing system, which allows mechanisation of labours but causing high environmental and landscape impacts. In this work, we approach some aspects of the changes that this modern farming system is causing in the region, which have repercussion on grape development. The impacts of land terracing on soil properties and the sustainability of the system as well as the repercussions on grape production are analysed.

MATERIALS AND METHODS

Study area: The study was conducted in the Priorat Qualified Designation of Origin region (Priorat QDO) NE Spain. The average slope of the terrain is about 25º. Climate is classified as Mediterranean temperate tending to continental, with an annual average temperature of 14.3ºC (annual average maximum and minimum temperatures of 18.8 ºC and 9.8 ºC, respectively) and an average rainfall about 520 mm mainly distributed in Spring and Autumn. Based on the Soil Taxonomy of the USDA (Soil Survey Staff, 1999), soils are classified as *Lithic Xerorthents*, developed on schist, which give the wines special distinctive characteristics. Soils are slightly acid (pH about 6) and poor in organic matter content in the surface horizon (less than 2%).

The vineyard surface has changed from 700 ha in the 1990 to 1767 ha at present, with about 95% cultivated with red varieties (mainly Grenache, Carignan, Cabernet Sauvignon, Merlot and Syrah). The grape increased from 2.5 Million kg in 2000 to 4.5 Million kg in 2008 (Priorat QDO, 2008). The wine production increased from 18600 HL in 2000 to 27698 HL in 2008. This sharp increase is a result of the introduction of new mechanised vineyard plantations taking over natural areas and traditional agricultural land.

Soil properties analysis changes: Soil surface properties were analysed in a new terraced vineyard and a traditional vineyard planted on a hillslope. The two plots were located in the Porrera municipality (UTM 31n Zone T: 322619, 4564575 - 323400, 4563021). The average slope of each plot was about 27º. On each plot, several points were considered uniformly distributed along the slope: 12 points on the terraced plot at six positions along the slope ranging from 298 m and 269 m a.s.l and seven points on the old vineyard-plot (OV) at distance ranging 289 and 419 m a.s.l.. At each position, soil surface properties (0-20 cm) were analysed. All samples were air dried and sieved using a 2-mm mesh. Soil pH, electrical conductivity (EC), particle size distribution without extraction of carbonates and organic matter content (OM) was evaluated in each soil sample. Aggregate stability (WSA) was evaluated following the method proposed by Kemper and Rosenau (1986). Water retention capacity at -33 kPa (FC) and -1500 kPa (WP) was evaluated in the fine soil fraction <2mm, using Richard plates. Bulk density (BD) was measured in situ by making a 25cm*25cm*15 cm hole in the soil and measuring soil mass and volume. From this information available water capacity (AWC) was calculated for each sample. The result was them referred to the total soil volume. Saturated hydraulic conductivity (Ks) was evaluated with a CSIRO disc permeameter 25-cm-diameter base.

Terracing design and its sustainability: The analysis of the new terracing system for vineyard plantation was carried out in the same terraced vineyard where the previous analysis was done. The survey was carried out two years after terracing. The terrace design parameters (spacing between terraces: vertical and horizontal intervals, slope of risers, slope of the terrain and width of the bench) were analysed for 20 terraces a across the field. A Geodimeter 422 total station, with ± 0.01 m accuracy was used to acquire the required data for assessing the dimensions of the terraces and the slope of the risers. In addition, another survey to locate and measure the soil and mass movements occurred in the study field was carried out. The location of the soil and mass movements were determined by a GPS Trimble GeoExplorer XT with differential correction, with an accuracy of less than 1 m. The dimensions (affected area and maximum and average soil depth removed) as well as the infrastructures and plants that were affected by the mass movements occurred on the riser were evaluated in the field.

Effects of land terracing in grapes: In order to asses changes in production and grape characteristics a survey of 38 plots planted with Carignan and 38 plots planted with Grenache was carried out during the years 2004-05, to 2007-08. Among these plots, 31.5 % and 47.3% corresponded respectively for each variety to new terraced vineyards. The rest were vineyard planted in the slope following the traditional system. For each plot, the following information was considered: harvest day, yield, pH, acidity, alcoholic degree.

RESULTS AND DISCUSSION

Changes in soil properties: The most remarkable characteristic of the analysed soils is their high percentage of gravels (>2 mm), ranging from 46.9 to 85.6% in both traditional and new terraced plots, with mean values ranging between 65.2% in traditional vineyards and 69.7% in terraced vineyards (Tab. 1). The soils were slightly acid, with pH values ranging between 4.4 and 7.6, being significantly lower in the old vineyards (4.6) than in the terraced plots (6.48). This could be due to the use of fertilisers or herbicides for a long time in those soils which are usually not ploughed. However, in the new terraced plots the soil now on top of the surface come from deeper layers of abandoned areas in which this kind of products were not used for a long time.

The electrical conductivity (EC) ranged between 0.09 and 0.17 dSm^{-1} at 25ºC, without significant differences between plots. The organic matter content (OM) was relatively low, with significantly lower values on the terraced plots (0.17%) than on the traditional vineyard plots (0.43 %) as a consequence of the levelling works. Bulk density was very variable within each plot, ranging between 1650 kg m^{-3} in the abandoned areas and 1756 kg m^{-3} on the terraced plots. The small increase observed on the new terraced plots could be due to compaction not only during the construction of the terraces but also during mechanised tilling.

The soil surface alterations produced by the terrace construction affected some hydrological properties. The changes in structure and bulk density, together with the low soil organic matter content after terracing, have a significant influence on some hydrological properties such as the available water capacity, the hydraulic conductivity and the aggregate stability.

Significant differences were observed between Ks values in the old vineyards 198 mm h^{-1}, and those observed in the new terraced vineyards 91 mm h^{-1}. Available water capacity (AWC) was also significantly reduced in the new situations: 17.2 mm in terraced vineyards *vs*. 22.8 mm and 57.7 mm in the old vineyards (Tab. 1). According to those figures and the critical values established for soils with a xeric regime (Porta et al., 1999), the AWC of terraced soils can be classified as very low (< 64mm), which forces the new management systems to have support irrigation. In the study soils, infiltration rates are very high even in the step slope areas. However, water retention capacity is really low, and although most of water infiltrate and water losses by runoff are very low, the available water content is scarce, which implies stress conditions for plants during long dry periods, in particular in the seasons were rainfalls is scarce and water needs are higher (late spring and summer).

Tab.1.Mean values and standard deviation of soil surface properties for new terrace vineyards (TV), old vineyards (OV), values referred to total soil mass.(n=number of sampling points)

Land use treat (n)	Texture (USDA)			Gravels (> 2mm) (%)	OM (%)	pH	EC (dSm-^{1})
	Clay (%)	Silt (%)	Sand (%)				
TV (12)	3.4±1.6 a	5.52±2.3 a	24.2±10.3 a	67.8±12.6 a	0.16±0.08 a	6.0±0.7 a	0.18±0.10 a
OV (8)	3.4±0.7 a	5.56±1.1 a	25.8±6.9 a	65.2±6.8 a	0.42±0.14 b	5.3±1.2 b	0.14±0.03 a

	Bulk Density (kg m^{-3})	FC (%)	WP (%)	AWC (mm)	WSA (%)	Ks (mm h $^{-1}$)
TV (12)	1640±160 a	13.9 ±8.6 a	8.6±6.2 b	17.2±7.5 a	21.4±11.0 ab	146.4±85.4 ab
OV (8)	1660±150 a	14.0 ±1.0 a	6.8±5.8 ab	22.8±18.3 a	27.4±5.6 b	198.3±88.1 b

The aggregate stability was significantly lower in the soils of the terraced plots (64.4%) than in the traditional vineyard (73.6% and 78.7%) when the >2mm soil mass is considered. Despite the low organic matter content in the analysed soils, a significant correlation was observed between WSA and OM. However, the changes observed in hydraulic conductivity and available water capacity cannot be explained only by the observed changes in texture and organic matter.

Terrace design: The field survey carried out to measure terrace design characteristics, shows a great variability in all analysed parameters (vertical and horizontal intervals, bench width, and riser slopes) (Tab. 2), and they seem not to follow a previous design. Terrace risers have average slopes of 39º (28-56º). In comparison with the original terrain slope degree at the measured terraces (average 29.2 ± 4.9 º), it supposes a local slope degree increment (at the risers) of about 33.6%. The average width of the benches is 2.9 m (2.0 - 4.61 m), with slope gradients of 1-3º. Typical terrace lengths (along the contour) measure 65-250 m (average 175 m).

The parameter showing the lowest variability is the bench width. This seems the only design characteristic taken into account to construct the terraces, probably conditioned by the target width necessary for tractors trafficability and the one that allows two vine rows per terrace: one row planted at the exterior edge of the bench and another row at the inner edge. The vertical and horizontal intervals between terraces, however, present high variability, with variations of about 50%. In comparison with published design criteria (Sheng, 1988), the terraces are not balanced between the vertical / horizontal intervals and the width of the benches. The observed VI and HI were higher than those calculated for reference criteria, and the HI/VI ratio was also higher than that suggested in the literature Hunri (1986), Sheng (1988) and Chan (1981). Sheng (1988) proposed that the ratio between the vertical and horizontal dimensions of the riser should be 0.75-1, but in the present case study this ratio is higher than 1 (1.2 on average).

In order to maintain the number of terraces, for the slope degree of the terrain and the slope degree of the risers, the width of the benches should be smaller. This would require the reduction of the cultivation surface, implying only one vine row per terrace, which is not accepted by farmers, because the number of plants would be reduced by 50% and because they want to use machinery for most of the labours, and with narrower benches the pass of tractors would not be possible. In addition, this would imply higher cost, near twice, because about 50% of the cost of a new plantation is due to land terracing works. For these reasons vine cultivators prefer to assume some geomorphological risk (riser slides or even terrace collapse, damages in infrastructures, burial of plants, etc.) instead of increasing the expensive man labour works. Therefore, the mechanization of labours and machinery trafficability seem to be the unique design criteria taken into account. Terrace risers are not protected by stone walls or natural vegetation, and mass movements and the collapse of the risers, may occur particularly in the cases in which there is not a balance between riser length and slope.

Tab. 2. Average design parameters of the bench terraces measured in the field.

Local slope before terracing S (º)	Vertical interval VI (m)	Horizontal interval (HI) (m)	Width of the bench Wb (m)	Slope of risers U (º)
29.2 ± 4.9 (18.3 –36.5)	4.82 ± 3.0 (2.4 –12.9)	6.2±3.5 (2.6-16.6)	2.94 ± 0.9 (2.37-5.91)	39.4 ± 8.7 U=1.21

Terracing sustainability: According to field observations mass movements or slides in the risers of the analysed terrace systems are frequent, even after non exceptional rainfall events. The survey carried out in the experimental field accounted for 73 mass movements of different magnitude along the slope. Twenty nine per cent occurred in the lower third of the slope, which represent 75% of the surface affected by mass movements. Fifty six per cent were located in the upper third of the slope, representing 20% of the total affected surface, and the rest occurred in the middle part of the slope. This distribution is most probably explained by the way as the terraces are constructed, starting from the top of the slope (upper part of the slope or water divide) to the bottom (lower part of the slope). This makes unconsolidated material resulting from cutting operations is being accumulated in the lower part of the slope. An exponential relationship between affected surface by mass movements and the length of the riser is observed. Mass movements cause damages in the plants and in the field infrastructures (training structures, irrigation tubes, paths). In the present case study, 319 plants out of 18500 in the field were affected, which represent 1.7%, being 97.5% of the affected located in the lower third of the slope (311 out of 4530 plants). The last rate represents 6.9% of the plants in that area. In addition, irrigation tubes and training structures were also damaged in the lower third of the hillslope. Also, some of the terraces have been jammed, obstructing the pass of the machinery in those terraces. Due to the high slope degree and the difficulties for heavy machinery traffic, restoration of the terraces has not been possible, being those zones abandoned. Similar mass movements may be observed in other new mechanized vineyards in the area, but under the same climatic conditions no signs of soil movements are produced in the old vineyards.

Land terracing and grape production: The analysis of information collected in the near 80 plots, despite the short time period and the differences in climate parameters recorded during the analysed years, shows some features. For both varieties, there are differences in yield between both new and old vineyards: 2.18 *vs* 0.68 kg/vine for Carignan and 2.34 *vs* 1.64 kg/vine for Grenache. For Carignan pH was on average 3.46 for the new vineyards and 3.51 for the old vineyards, with higher differences in the acidity (5.29 *vs.* 4.22). For Grenache, pH values were 3.3 *vs* 3.24 and acidity 5.18 *vs* 4.69. Lower differences were found in the alcoholic degree although it was always higher in the old vineyards (14.5 and 14.9 for Carignan and Grenache, respectively) than in the new vineyards (13.7 and 14.5 for Carignan and Grenache, respectively).

CONCLUSIONS

The new land terracing system involves a complete alteration of the hillslope morphology and high economic investment to adapt fields to mechanisation. Soil hydrological properties are significantly affected, which have a negative repercussion on water availability for plants. A significant reduction on the hydraulic conductivity and on available water capacity is produced, being up to 45% lesser in the terraced vineyards than in the old ones. The analysis also highlights the decrease in the OM content, being by up to 50% lower in the terraced vineyards. Effects of the new plantation systems are also affecting yield and grape qualities.

In addition, the terracing system is not implemented under a conservative point of view but only looking for to allow mechanized works. Terraces are constructed with higher risers and widths than those expected for the high slopes degrees existing in the area, with the results of landslides after not very few rainfall events. The maintenance or restoration of the risers is not carried out due to the difficulties for heavy machinery accessibility and to avoid further damage to infrastructures such as irrigation, training systems and vines, damaged by mass movements.

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