Available online at www.sciencedirect.com
ScienceDirect
Geoderma 142 (2007) 251–261
GEODERMA
www.elsevier.com/locate/geoderma

Effects of land terracing on soil properties in the Priorat region in Northeastern Spain: A multivariate analysis

María Concepción Ramos *, Roser Cots-Folch, José A. Martínez-Casasnovas

University of Lleida, Environment and Soil Science, Alcalde Rovira Roure 1991, 25198 Lleida, Spain

Received 28 June 2006; received in revised form 18 May 2007; accepted 5 August 2007
Available online 29 September 2007

Abstract

The Priorat region, a traditional area for wine production in the Mediterranean mountain environment of NE Spain, has been undergoing drastic changes since the 1990s, with the conversion of abandoned and natural vegetation areas into new terraced vineyard plantations. In most cases, these land cover changes involve land terracing, with risers more than 2 m high and benches with the soil surface structure completely altered. The objective of this work is to analyse the impacts of these land transformations on soil physical properties such as texture, water retention and infiltration capacity in a sample area of the region. Soils are classified as Lithic Xerorthents and are locally called "llicorell". For this study two different situations on a 100-m-long hillslope were studied: one in an undisturbed position, with natural vegetation and one in a disturbed two-year-old terraced vineyard. Samples of the soil surface from 0 to 20 cm were collected at several points along the slope for analysis of texture, organic matter and aggregate stability. At these locations, saturated hydraulic conductivity was measured using a disc permeameter. The results show that in these soils with a high percentage of coarse elements (>60%), work carried out during land transformation produced changes in the particle size distribution of the fine fraction. In addition, levelling reduced the organic matter content of the cultivated soils. These changes affected hydraulic conductivity, water retention capacity (which decreased by 45%) and aggregate stability, as well as the relationships between all these variables.

Keywords: Land terracing; Mechanised vineyards; Aggregate stability; Hydraulic conductivity; Water retention capacity; Multivariate analysis

1. Introduction

The radical changes that European agriculture has undergone in the last few decades have entailed large-scale processes of land-use and land-cover change (LUCC). These changes are leading to major landscape modifications, land degradation and new management techniques as a result of the abandonment of traditional practices and the intensification of more productive land (García-Ruiz et al., 1996; Zalidis et al., 2002; Borselli et al., 2006). In the Mediterranean region, these changes act as one of the main environmental degradation forces through the impacts on soil and water resources (Zalidis et al., 2002) and biodiversity (Bielsa et al., 2005).

Specifically, agricultural land intensification has emerged as a consequence of technological progress and the socio-economic constraints of adapting fields to make them competitive in the framework of new national and international market prospects. This process requires earth movements (land levelling and/or land terracing operations) to prepare the area for new cultivation, and management to implement the new land use through the removal of unwanted vegetation and field boundaries, etc. (Borselli et al., 2006). In some cases, these changes are supported by the Common Agricultural Policy (CAP), which gives various incentives and subsidies that affect not only agricultural land use but also the rural landscape (Busch, 2006).

In the Mediterranean region, vineyards are one of the main crops which during the last decade have suffered significant land transformations (Martínez-Casasnovas and Sánchez-Bosch, 2000; Pla and Nacci, 2003). They have been stimulated by the EU Common Agricultural Policy, through the restructuring and conversion plans (Commission Regulation EC No. 1227/2000 of 31 May 2000, which specifies detailed rules for

---

* Corresponding author. Tel.: +34 973702092; fax: +34 973702613.
E-mail address: cramos@macs.udl.es (M.C. Ramos).

0016-7061/$ - see front matter © 2007 Elsevier B.V. All rights reserved.
doi:10.1016/j.geoderma.2007.08.005

the application of Council Regulation EC (1493/1999) as regards production potential) that support the large economic cost of implementation of such operations.

One clear example of drastic transformation to adapt land for new vineyard plantations is the Priorat Qualified Designation of Origin (Priorat QDO). The Priorat is a traditional area for wine production in Catalonia, NE Spain, where vineyards have been cultivated since the 12th century. The period of maximum expansion was in the 19th century, when vineyards occupied up to 75% of the land and entirely transformed the Priorat landscape (Figueras and Calvó, 2003). During the first half of the 20th century, the sector underwent a crisis that led to a major deintensification of land use and the abandonment of agricultural land (Douglas et al., 1996). This situation was only partially overcome in the 1990s, when a small group of producers introduced new vinification and marketing techniques that pushed the wines towards the top of the international market. This has attracted producers from other areas who have been buying land during the last decade to create new mechanised plantations systems.

Heavy machines such as bulldozers are being used for large-scale earth movements in order to create new terracing systems for vineyards. The new terraces have average risers more than 2.5 m high, with no protection and slopes of about 36°. The earth movements are not controlled by any law or technical guidelines and are determined by the needs of the owner or the person on charge of the machinery. The movements account for about 77,750 m^3 ha^{-1} (Cots-Folch et al., 2006). Those works modify the soil surface characteristics, which influence the infiltration properties at the surface (Poesen et al., 1990; Léonard and Andrieux, 1998; Malet et al., 2003) and interact with other geomorphological processes such as erosion (Lundekvam et al., 2003) and mass movements, mainly during extreme precipitation events (Abreu, 2005). The spatial variability created by all these operations leads to heterogeneous infiltration and runoff responses on hillslopes. The soil redistribution also modifies the soil slope stability and the stability of the terraces, increasing the risk of surface mass movements.

Some studies have pointed out the spatial variability of soil properties along the hillslopes (Agbenin and Tiessen, 1995; Bartoli et al., 1995) and with the slope degree (Janeau et al., 2003). However, there are no studies documenting the effects of the new mechanised terracing systems on soil properties. We could expect accumulative effects produced by the redistribution of the soil such as some authors have pointed out to some extent by studies on tillage erosion (Van Muysen et al., 1999; Torri et al., 2002; De Alba et al., 2004) on slow-forming terraces (Dercon et al., 2003), on compaction due to the use of heavy machinery (Ferrero et al., 2005) or by translocation caused by terracing on steep slopes. All these operations give rise to gradients in soil properties from the upper to the lower parts within the plots (Thapa et al., 1999; Turkelboom et al., 1997), even affecting soil productivity (Turkelboom et al., 1996).

To cover this gap in new mechanised terracing systems, the objective of the present work is to analyse the impact of land terracing on soil physical properties such as water stable aggregates, water infiltration and retention capacity by comparing the same properties in old traditional vineyards and forest areas that conserve the natural soil and slope morphology and the new terraced vineyards resulting from earth movement operations in a sample area of the Priorat QDO, (northeastern Spain).

2. Materials and methods

2.1. Study area

The study was conducted in the Priorat Qualified Designation of Origin region (Priorat QDO, Catalonia, NE Spain) (Fig. 1). It is a depression formed in the split of the southern part of the Montsant mountain chain. The average slope of the terrain is about 25°. Climate is classified as Mediterranean temperate tending to continental, being characterised by dry winds, mainly from the NE, and an annual average temperature of 15 °C (ranging from 6 to 23 °C). Average rainfall is about 600 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, locally called “llicorell”, which give the wines special distinctive characteristics. Soils are slightly acid (pH about 6) and the organic matter content in the surface horizon is less than 2%.

Traditionally, the landscape has been a mosaic of traditional agriculture and natural vegetation (Iglésies, 1975). The main agricultural use is vineyards (*Vitis vinifera*), with Grenache, Carignan, Cabernet Sauvignon, Merlot and Syrah as the main varieties. The vineyard surface has changed from 700 ha in the 1990 to 1650 ha at present and the wine production increased from 18600 HL in 2000 to 29000 HL in 2004 (Priorat QDO, 2005). This sharp increase is a result of the introduction of new mechanised vineyard plantations taking over natural areas and traditional agricultural land.

2.2. Soil sampling

The assessment of land transformation effects on soil hydrological properties was carried out in three plots with a convex-concave slope in the municipality of Porrera (318900, 4562900 UTM 31n zoneT) (Fig. 1). One plot consisted of an old vineyard cultivated on hillslopes according to the traditional system. The other two plots consisted of new terraced vineyards, in which a different degree of land transformation on the soil surface could be observed: in one of them soil surface was mechanically crushed using a stone-crusher machine to leave on top of the surface soil particles less than 30 mm. In addition, the same characteristics were analysed in a forest area and in an abandoned area, which had been previously cultivated with hazel nuts but at this time was covered with natural vegetation.

The average slope of each plot was about 27°. On each plot, several sampling points were considered uniformly distributed along the slope: 12 points on terraced plots with crushed material on the surface (TVc) at 6 positions along the slope ranging from 269 m to 298 m a.s.l; 12 points on terraced vineyard plots without crushed surface material (TV), at 6 positions ranging from 309 m to 463 m a.s.l.; 7 points on the old

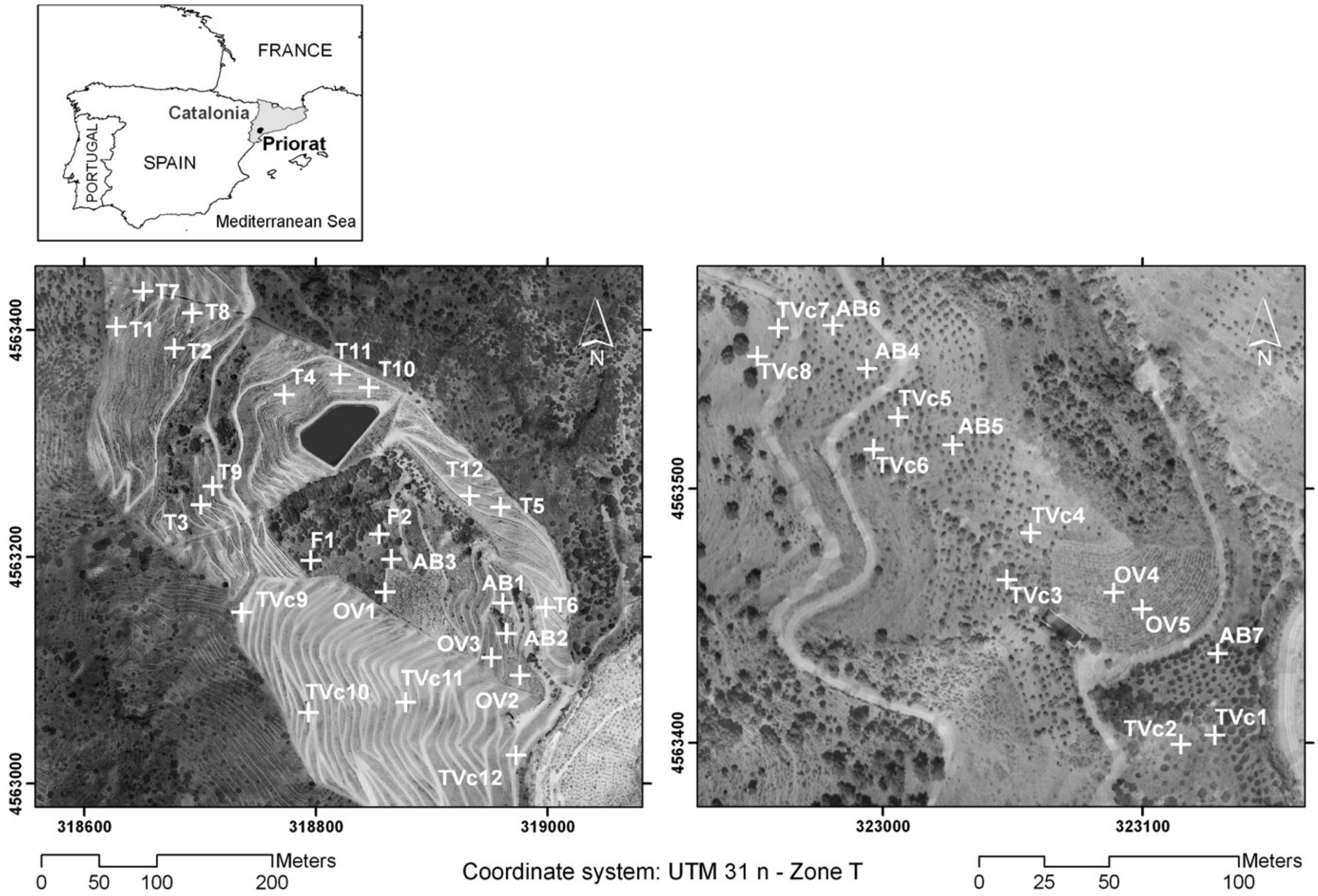

Fig. 1. Location of the study fields in the municipality of Porrera, Priorat QDO (NE Spain).

vineyard-plot (OV) at positions ranging 289 m to 419 m a.s.l. and 6 points on an abandoned non-cultivated area covered with forest vegetation (AB) located between 360 m and 489 m a.s.l. The locations of the sampling point are indicated in Fig. 1.

2.3. Soil characteristics

At each position, surface soil samples (0–20 cm) were taken for laboratory analysis. All samples were air dried and sieved using a 2-mm mesh. The following parameters were analysed: Soil pH and electrical conductivity (EC), were determined in a water suspension of soil using a 1:5 soil/solution ratio ($EC_{1:5 \text{ water extract}}$). Particle size distribution without extraction of carbonates was analysed according to (Gee and Bauder, 1986), organic matter was previously destroyed and then extracted with Na hexametophosphate. Organic matter content (OM) was evaluated following the method proposed by (Nelson and Sommers, 1982) (OM = Organic carbon * 1.72). Aggregate stability was evaluated following the standard method (Kemper and Rosenau, 1986) using 1–2 mm diameter aggregates (OSM), saturated and placed in a Yoder apparatus. The material remaining on the sieve after 3 min raised and lowered trough a 1.3-cm vertical distance at 36 cycles/min was oven-dried (105 °C) and weighed (stable aggregate mass = SA). Then this material was dispersed by sonication in distilled water three times for 10 min each and sieved. The fraction remaining on the 0.25 mm sieve was oven-dried and weighed to obtain the mass of > 0.25 mm sand (SM). The water stable aggregate percentage (WSA) was calculated by the Eq. (1):

$$\mathrm{WSA} = \frac{\mathrm{SA} - \mathrm{SM}}{\mathrm{OSM} - \mathrm{SM}} * 100 \qquad (1)$$

where: WSA = water stable aggregate percentage (%); SA = stable aggregate mass; SM = mass of > 0.25 mm sand; OSM = original soil mass.

In addition, water retention capacity at −33 kPa (FC) and −1500 kPa (WP) were evaluated in the fine soil fraction < 2 mm), using Richard plates. Bulk density (BD) was measured in situ by making a 25 cm * 25 cm * 15 cm hole in the soil and measuring soil mass and volume (Pla, 1983; Blake and Hartge, 1986). Soil mass was measured after dried at 105 °C for 24 h. Volume was measured by filing the whole, previously recover with plastic film, with distilled water. From this information (water retention capacity (WRC—33 kPa and WRC—1500 kPa) and bulk density (BD)) available water capacity (AWC) was calculated for each sample according to Eq. (2).

$$\mathrm{AWC} = [(\mathrm{WRC}_{-33\mathrm{kPa}}) - (\mathrm{WRC}_{-1500\mathrm{kPa}})] * \mathrm{BD} * \mathrm{SD} \qquad (2)$$

where: AWC = available water capacity (kg water/kg soil); $\mathrm{WRC}_{-33\ \mathrm{kPa}}$ = water retention capacity at −33 kPa (%)

(field capacity); $\mathrm{WRC}_{-1500\ \mathrm{kPa}}$ = water retention capacity at −1500 kPa (%) (wilting point); BD = bulk density (kg soil/m^3); SD = soil depth (m).

The results were them referred to the total soil volume. For this calculation the results observed by Fonseca (2006) related to the water retention capacity of the different particle size of these soils were taken into account. He found that the fraction <2 mm retained most of water (85% on average at −33 kPa and 84% at −1500 kPa), which is in agreement with the results obtained for stony soils by Cousin et al. (2003), who pointed out that when hydraulic properties are neglected percolation can be overestimated up to 15.8%. Saturated hydraulic conductivity (Ks) was evaluated with a CSIRO disc permeameter for saturated infiltration with a 25-cm-diameter base (Perroux and White, 1998). A thin (5 mm) moist contact sand layer was applied to the soil surface to cover exposed rock edges and to provide a better surface contact. Ks was determined from measured infiltration rates.

2.4. Statistics

A statistical analysis (mean tests and ANOVA analysis) was performed in order to confirm significant differences. The least-significant differences (LSD) option of the ANOVA was used as a test of significance of differences among means (significant differences at 95% level were analysed). In addition, a multivariate analysis (principal component and cluster analysis) was made to analyse the relationship between the studied variables and the changes caused by the mechanical operations. The analysis was carried out using the STATGRAPHICS 5.1 software.

Both principal component analysis (PCA) and cluster analysis (CA) are widely used in environmental studies for classification, modelling and evaluation. Principal component analysis (PCA) reduces the dimensionality by revealing several underlying components, which are called principal components. Each principal component (PC) is described in terms of p new components (Fi), which are defined as a linear combination of the original variables. The first component, associated with the larger eigenvalue, accounts for the maximum of the total variance; the second component is the second linear combination, uncorrelated with the first, which accounts for the maximum of the residual variance, and so on until the total variance is accounted. Usually, a small number of components explain a high percentage of the total variance; that is, the data set can be described in a smaller-dimensional space. In order to facilitate the interpretation of each component, Varimax Rotation was applied. The data were standardised to zero mean and unit variance. A first principal component analysis of all samples belonging to all land use treatments were performed, in order to see if there were differences between land use treatments. The factor scores of the retained PC were analysed. From the observed results the samples were separated into two data sets depending on the soil modification: terraced vineyards (treatments TV + TVc) and old vineyard + abandoned areas with natural vegetation (cultivated on the original hillsplope) (treatments OV + AB).

For cluster analysis (CA), a hierarchical cluster technique was used (Massart and Kaufman, 1983). The purpose of cluster analysis (CA) is to place objects into groups in which the objects show some similarity to each other. The dissimilarity between them is a distance measure. The hierarchical cluster technique uses a Euclidean distance metric to separate a set of objects into groups according to chosen criteria. Among the different methods, two aggregation criteria were used: the group-average method and Ward's minimum variance method. Both have been pointed out as methods that give good results (Milligan, 1980).

The group-average method is a weighted method which calculates the distance between two clusters as the arithmetic average distance from observations in one cluster to observations in another cluster. This method tends to combine clusters that have small variances and may produce clusters that have the same variance. Ward's method calculates the distance between two clusters as the sum of squares between the two clusters added up over all the variables. At each generation, the within-cluster sum of squares is minimised over all partitions obtainable by merging two clusters from the previous generation. This method tends to join clusters with a small number of observations and is strongly biased towards producing clusters with a similar number of observations. This method attempts to minimize the Sum of Squares (SS) of any two (hypothetical) clusters that can be formed at each step. In general, this method is regarded as very efficient, but it tends to create clusters of small size. In both cases the results were presented by a dendogram, a two-dimensional figure that represents the sequence and the distance at which the observations are clustered.

The variables included in the analysis were the physical characteristics of the soil analysed in each land use treatment: proportion of water stable aggregates (WSA); water retention capacity at −33 kPa (field capacity) (FC); water retention capacity at −1500 kPa (wilting point) (WP); available water capacity (AWC); saturated hydraulic conductivity (Ks); bulk density (BD); organic matter content (OM); and particle size distribution (proportion of clay, silt, sand and gravels). The values used in this analysis were referred to total soil mass. The hierarchical technique was carried out using standardised data to zero mean and unit variance in two series: terraced vineyards (treatmentsTV + TVc) and old vineyard + abandoned areas with natural vegetation (treatments OV + AB). The average values of each variable in each cluster as well as the characteristics of the sampling points included in each of them were taken into account to interpret the results.

3. Results and discussion

3.1. Changes in soil characteristics

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% (CV = 0.10) in traditional vineyards and 69.7% in terraced vineyards (CV = 0.18) (Table 1).

Different letters indicate significant differences at 95% level of significance. No significant differences were observed between the undisturbed plots (old vineyards and abandoned plots with natural vegetation) and the disturbed plots (new terracing systems). In spite of this, the gravels of 2–8 mm size were significantly lower on the new terraced plots than on the old vineyards and abandoned fields. This is due to the work carried out to prepare the soil surface, which involved scratching and extraction of rocky material. The percentage of gravels (>2 mm) decreased from top to bottom in the undisturbed plots and in those terraced vineyards in which the material was not crushed. These results are in agreement with those observed by Ampontuah et al. (2003) on arable hillslopes.

The soils are slightly acid, with pH values ranging between 4.4 and 7.6, being significantly lower in the old vineyards (4.6±0.22, CV=0.048) than in the terraced plots (6.48±0.28, CV=0.043) or in the abandoned areas (6.61±0.55, CV=0.083). The lower pH in the old vineyards 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 topsoil horizons come from deeper layers of abandoned lands where these products had been not used for a long time. This result is in agreement with that found by Sevink et al. (1998) in a study carried out near to our study area. These authors found differences between the soil surface (pH ranging form 4.5 to 5) and the deeper layers (pH near 6). In our study case, in the terraced vineyards the deeper layers are now on the surface. The electrical conductivity (EC) ranged between 0.09 and 0.17 dS m^{-1} at 25 °C, without significant differences between land use treatments (0.16, CV=0.5 in terraced soils and 0.09, CV=0.33, in abandoned areas). The organic matter content (OM) was relatively low, with significantly lower values on the terraced plots (0.17%, CV=0.47) than on the traditional vineyard plots (0.43%, CV=0.30) and in the soils of abandoned areas (0.48%, CV=0.61), as a consequence of the levelling works.

Bulk density was very variable within each plot, ranging between 1650±310 kg m^{-3} (CV=0.19) in the abandoned areas and 1756±158 kg m^{-3} (CV=0.09) on the terraced plots (Table 2). 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 and other crop labours. These results are also confirmed by other studies carried out in other new terraced fields in the Priorat QDO (Abreu, 2005). In the traditional vineyards the bulk density was similar to that in the abandoned areas (1650 kg m^{-3}).

The changes in structure and bulk density, together with the low organic matter content of the soils after the terracing, have a significant influence on some hydrological properties such as the available water content (AWC), the hydraulic conductivity (Ks) and the aggregate stability (WSA) (Table 2). Different letters indicate significant differences at 95% level of significance. Significant differences were observed between Ks values of the abandoned areas (403 mm h^{-1}, CV=0.24) or in old vineyards 198 mm h^{-1}, CV=0.44) and those observed in the new terraced vineyards, being the last the lowest measured values: 91 mm h^{-1} (CV=0.48) in those with crushed material on top *vs.* 146 mm h^{-1} (CV=0.58) in those without crushed material on top. These values as well as their high variability are of the same order of magnitude to those found by other authors in stony soils (Sauer and Logsdon, 2002), with high proportion of gravels.

Table 1

Mean values, standard deviation and coefficient of variation (CV) of soil particle distribution, organic matter content (OM), pH and electrical conductivity (EC) for each land use treatment: new terraced vineyards (TV), new terraced vineyards with crashed material on top of the surface (TVc), old vineyards (OV), abandoned areas with natural vegetation(AB), number of sampling points (*n*)

Land use treatment (*n*)	Texture (USDA)			Gravels (>2 mm) (%) (CV)	OM (%) (CV)	pH (CV)	EC (d Sm^{-1}) (CV)
	Clay (%) (CV)	Silt (%) (CV)	Sand (%) (CV)				
Values in <2 mm soil mass							
TV (12)	9.2 ± 3.3^{a}	16.8 ± 3.8^{a}	74.4 ± 5.2^{a}	67.8 ± 12.6^{a}	0.9 ± 0.4^{a}	6.0 ± 0.7^{a}	0.18 ± 0.10^{a}
	(0.36)	(0.23)	(0.07)	(0.18)	(0.44)	(0.12)	(0.56)
TVc (12)	11.2 ± 3.8^{a}	18.9 ± 3.5^{a}	69.8 ± 6.3^{a}	69.7 ± 8.9^{a}	0.6 ± 0.5^{a}	6.5 ± 0.3^{a}	0.16 ± 0.08^{a}
	(0.34)	(0.09)	(0.09)	(0.12)	(0.83)	(0.05)	(0.50)
OV (8)	9.0 ± 3.4^{a}	18.7 ± 4.9^{a}	72.3 ± 5.6^{a}	65.2 ± 6.8^{a}	1.2 ± 0.4^{b}	5.3 ± 1.2^{b}	0.14 ± 0.03^{a}
	(0.38)	(0.08)	(0.09)	(0.10)	(0.33)	(0.19)	(0.21)
AB (6)	6.5 ± 0.7^{a}	23.1 ± 2.5^{a}	70.4 ± 1.9^{a}	67.4 ± 3.8^{a}	1.8 ± 1.1^{b}	6.6 ± 0.5^{a}	0.09 ± 0.03^{b}
	(0.11)	(0.03)	(0.03)	(0.05)	(0.61)	(0.08)	(0.33)
Values referred to total soil mass							
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}
	(0.47)	(0.42)	(0.43)	(0.18)	(0.50)	(0.12)	(0.56)
TVc (12)	2.5 ± 0.8^{a}	5.86 ± 2.4^{a}	20.8 ± 5.1^{a}	69.7 ± 8.9^{a}	0.18 ± 0.13^{a}	6.5 ± 0.3^{a}	0.16 ± 0.08^{a}
	(0.32)	(0.41)	(0.25)	(0.12)	(0.72)	(0.05)	(0.50)
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}
	(0.21)	(0.20)	(0.27)	(0.10)	(0.33)	(0.23)	(0.21)
AB (6)	2.1 ± 0.1^{a}	7.59 ± 1.6^{a}	22.8 ± 2.2^{a}	67.4 ± 3.8^{a}	0.57 ± 0.30^{b}	6.6 ± 0.6^{a}	0.09 ± 0.03^{b}
	(0.05)	(0.21)	(0.10)	(0.05)	(0.53)	(0.09)	(0.33)

Different letters indicate significant differences between land use treatment.

Table 2
Mean values, standard deviation and coefficient of variation (CV) of some soil properties: bulk density; saturated hydraulic conductivity (Ks), water retention capacity at −33 kPa (FC) water retention capacity at −1500 kPa (WP); available water capacity (AWC) of soil surface; aggregate stability in <2 mm soil mass (WSA) of each land use treatment-new terrace vineyards (TV), new terraced vineyards with crashed material on top of the surface (TVc), old vineyards (OV), abandoned areas with natural vegetation (AB)-, number of sampling points (*n*)

Land use treatment (*n*)	Bulk density (kg m^{-3})	FC (%) (CV)	WP (%) (CV)	AWC (mm) (CV)	WSA (%) (CV)	Ks (mm h^{-1}) (CV)
Values in <2 mm soil mass						
TV (12)	1640 ± 160^{a}	31.8 ± 20.1^{a}	17.9 ± 1.3	44.5 ± 26.2^{ab}	64.4 ± 13.0^{a}	146.4 ± 85.4^{ab}
	(0.10)	(0.63)	(0.07)	(0.59)	(0.20)	(0.58)
TVc (12)	1756 ± 160^{a}	14.7 ± 7.6^{b}	7.2 ± 1.5	26.4 ± 4.0^{a}	52.5 ± 17.3^{ab}	91.4 ± 44.1^{a}
	(0.09)	(0.52)	(0.14)	(0.15)	(0.33)	(0.48)
OV (8)	1660 ± 150^{a}	41.6 ± 23.9^{a}	18.3 ± 1.8	78.8 ± 33.9^{b}	78.8 ± 7.7^{b}	198.3 ± 88.1^{b}
	(0.09)	(0.57)	(0.10)	(0.43)	(0.10)	(0.44)
AB (6)	1650 ± 310^{a}	30.4 ± 21.4^{a}	25.0 ± 3.4	131.1 ± 27.7^{c}	73.6 ± 12.5^{b}	403.2 ± 95.8^{c}
	(0.19)	(0.70)	(0.14)	(0.21)	(0.17)	(0.24)
Values referred to total soil mass						
TV (12)	1640 ± 160^{a}	13.9 ± 8.6^{a}	8.6 ± 6.2^{a}	17.2 ± 7.5^{a}	21.4 ± 11.0^{a}	146.4 ± 85.4^{ab}
	(0.10)	(0.62)	(0.72)	(0.44)	(0.51)	(0.58)
TVc (12)	1756 ± 160^{a}	6.2 ± 1.3^{b}	3.1 ± 0.8^{b}	10.97 ± 2.5^{a}	16.15 ± 8.9^{ab}	91.4 ± 44.1^{a}
	(0.09)	(0.21)	(0.26)	(0.23)	(0.55)	(0.48)
OV (8)	1660 ± 150^{a}	14.0 ± 1.0^{ab}	6.8 ± 5.8^{b}	22.8 ± 18.3^{a}	27.4 ± 5.6^{ab}	198.3 ± 88.1^{b}
	(0.09)	(0.07)	(0.85)	(0.80)	(0.24)	(0.44)
AB (6)	1650 ± 310^{a}	28.0 ± 1.70^{c}	11.3 ± 1.0^{b}	57.7 ± 14.0^{a}	23.9 ± 4.5^{b}	403.2 ± 95.8^{c}
	(0.19)	(0.06)	(0.09)	(0.24)	(0.19)	(0.24)

Different letters indicate significant differences between land use treatment.

Available water capacity (AWC) was also significantly reduced in the new situations: 17.2 mm (CV = 0.44) in terraced vineyards and 10.9 mm (CV = 0.23) in terraced vineyards with crushed material *vs*. 22.8 mm (CV = 0.80) and 57.7 mm (CV = 0.24) in the old vineyards and abandoned areas. 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 (<64 mm), which forces the new management systems to have support irrigation. In the study area, water infiltration rates are very high (Abreu, 2005), even in the step slope areas. The presence of rock fragments on the soil surface prevents from sealing and, as in most cases these steep slopes are not ploughed, the porosity is maintained, which favours water infiltration. However, in the disturbed soils, the removal of rock fragments leads to a decrease in infiltration because part of the porosity has disappeared and the soil surface has less protection.

However, water retention capacity is really low. The volumetric percentage of the rock fragments in the soil usually has a negative influence on the AWC. For soils developed on schist, Hanson and Blevins (1979) pointed out that the available water for plants not always decreases when the percentage of rock fragments increases, which was not observed in the study case. However, other factors such as the size and the position of the rock fragments, on the surface or inside the soil profile has a large influence on the total water (Poesen and Lavee, 1994). In the study case, although most of water infiltrate and water losses by runoff are very low the available water content is scarce, and in the cases in which the topsoil material was crushed, decreasing the rock fragments size, water retention did not increase. AWC and also hydraulic conductivity decreased, mainly due to the alteration of the soil porosity and the soil particle distribution within the soils. The alterations on AWC may imply 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).

Proportions of water stable aggregates were lower in the terraced plots (WSA value of 64.4%, CV = 0.20 and 52.5%, CV = 0.33 in the uncrushed and crushed new vineyard topsoils, respectively) than in the old vineyard topsoils and the topsoils developed on abandoned areas with natural vegetation (WSA values of 73.6%, CV = 0.17 and 78.7%, CV = 0.1, respectively) Significant differences at 95% level were confirmed when the <2 mm soil mass was considered. However, if the data were referred to total soil mass the differences were only significant between terraced soils with crushed material on the top (mean WSA = 16.1%) and in the traditional vineyards (mean WSA = 27.3%). The other two land use treatments gave intermediate values: 21.3% in terraces soil and 23.9% in the forest or the abandoned fields (Table 2). Despite the low organic matter content in the analysed soils, a significant correlation was observed between WSA and OM. This result is in agreement with that found by different authors in various soils types and managements (Tisdall and Oades, 1982; Chaney and Swift, 1984; Elwell, 1986; Bartoli et al., 1988; Dutartre et al., 1993), who showed a strong association between organic C and water stable aggregates. Nevertheless, water stable aggregates in the study soils are very low when they are referred to total soil mass, although the observed values in <2 mm soil mass may classify the soils of moderate stability.

On the other hand, other authors indicated the relationship between the organic matter content and some physical soil properties, such as soil porosity, structure and water-holding capacity (Tisdall and Oades, 1982; Diaz et al., 1994; León-

González et al., 2000; Ouédraogo et al., 2001; Nyamangara et al., 2001), as well as biological activity (Carpenter-Boggs et al., 2000). In our study, the changes observed in hydraulic conductivity and available water capacity cannot be explained only by the observed changes in texture and organic matter. Although the increase in the fine silt fraction could help to seal the soils, the interpretation should include additional information about the changes in the pore redistribution and the break of the natural water circulation channels in the soil profile.

3.2. Relationship between variables under different land use treatments: multivariate analysis

3.2.1. Principal component analysis

The principal component analysis of all topsoil samples allowed the similarity between the soil samples belonging to different land use treatments to be known (Fig. 2). A clear difference between the samples belonging to the abandoned areas and most of samples belonging to the traditional vineyards was observed, being the rest of samples related to terraced vineyards highly correlated (without differences between soil surface crushed and uncrushed). Using the factor scores obtained in this PC analysis for the four first principal components, which represented 86.5% of the total variance, significant differences were observed between terraced soil and the rest of samples (Fig. 3). Due to the lack of significant differences between crushed and uncrushed terraced vineyard soils and between old vineyards and abandoned areas, two groups were considered in the following analysis: terraced vineyards (after land levelling and terracing operations: disturbed) and old vineyards+ abandoned areas (without previous land levelling or soil alteration works: undisturbed). Principal component analysis of the variables of both series shows the relationship between them in each land use treatment.

For the undisturbed areas, three components were retained with eigenvalues higher than one (Kaiser's rule; Kaiser and Rice, 1974), explaining 78.8% of total variance. The communality of all variables was higher than 0.5. Loading factors after varimax rotation and the eigenvalues are shown in Table 3. The first principal component, which represented 46.81% of the total variance, showed high values for the variables related to water retention capacity and hydraulic conductivity (FC, WP, AWC, Ks), which were positively correlated with the proportion of silt content and negatively correlated with the proportion of clay content. The second principal component, with 21.17% of total variance, showed high loading values of the parameters related to water aggregate stability and organic matter content, which were negatively correlated with bulk density.

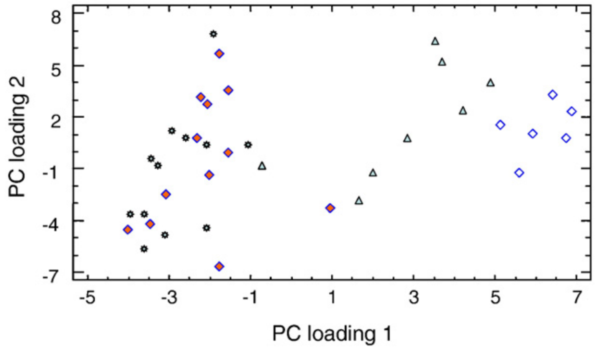

Fig. 2. Dispersion diagram of soil samples after PCA analysis of all topsoil soil samples: * terraced vineyards; ◆ terraced vineyards with crushed material on top of the surface; ▲ old vineyard plot; ◇: abandoned area.

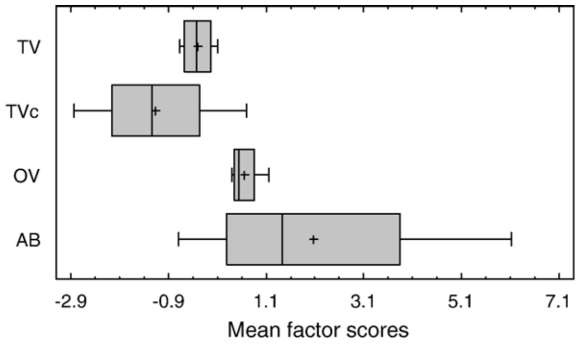

Fig. 3. Differences between land use treatments according to the factor scores of the principal component analysis of all soil samples. The first four PC, representing 86% of total variance were retained (terraced vineyards (TV), terraced vineyards with crushed material on top of the surface (TVc), old vineyards (OV) and abandoned areas with natural vegetation (AB).

The third component was associated with the proportion of sand in the soil. Fig. 4 shows the projection of components 1 and 2 for the undisturbed areas. If the number of principal components were increased up to four, the bulk density would change from PC1 to PC2, but the relationship between OM and WSA were lost, appearing the OM in a separate cluster.

For new mechanised terraced vineyards, following Kaiser's rule (Kaiser and Rice, 1974), three principal components which explain 73.7% of the total variance were retained.

Table 3
Varimax rotated principal component loading (PCi) for the three first components (old vineyards + abandoned areas-undisturbed soils)

	PC 1	PC 2	PC 3	Estimated communality
AWC	**0.956201**	−0.0962936	0.0183493	0.92393
WP	**0.778532**	0.266859	−0.204359	0.979139
FC	**0.957782**	0.233773	−0.198279	0.719089
Clay	**−0.927319**	−0.198279	0.165086	0.926489
Silt	**0.827418**	−0.124595	0.127722	0.716457
Sand	−0.0524379	0.0386224	**0.937068**	0.882339
WSA	−0.0081158	**0.825064**	0.0283844	0.681602
Ks	**0.660934**	−0.0355872	−0.495617	0.683737
OM	0.0735394	**0.754417**	−0.012829	0.574718
BulkDens	−0.109143	**−0.887234**	−0.027368	0.799845
Eigenvalue	4.68122	2.11678	1.08934	
% total variance	46.812	21.168	10.893	
%cum. Variance	46.812	67.980	78.87	

AWC: available water content; FC: water retention at −33 kPa; WP: water retention at −1500 kPa; Ks: saturated hydraulic conductivity; WSA: proportion of water stable aggregates; OM: organic matter content; BulkDens: bulk density; Clay; proportion of clay; Silt: proportion of silt; Sand: proportion of sand (all values are referred to total soil mass).
Loading factors higher than 0.5 (absolute value) are shown in bold.

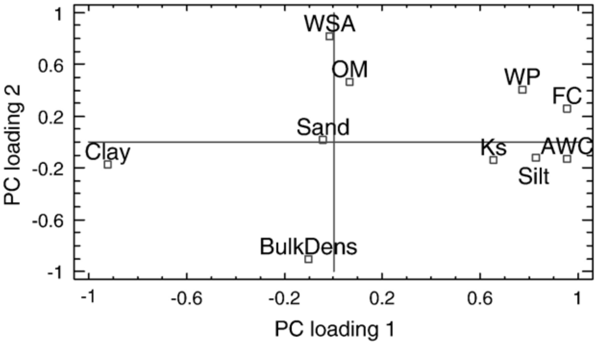

Fig. 4. Varimax rotated principal component loadings: PC loading 2 *vs*. PC loading 1 (for old vineyards+abandoned areas with natural vegetation).

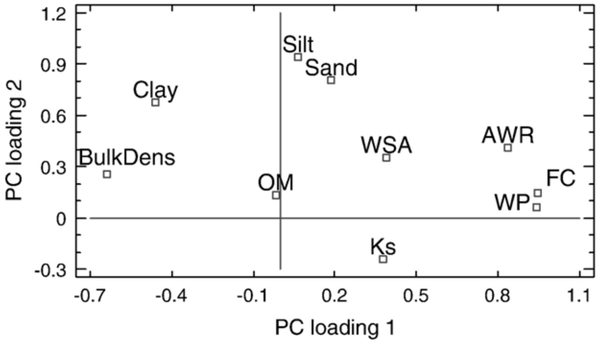

Fig. 5. Varimax rotated principal component loadings: PC loading 2 *vs*. PC loading 1 (for terraced vineyards-disturbed soils).

Loading factors after varimax rotation and the eigenvalues are shown in Table 4. The first component, explaining 38.9% of total variance, showed high loading values for the variables associated with water retention capacity (WRC, FC and WP) which were negatively correlated with bulk density. The second component, which accounted for 24.03% of total variance, was associated with soil particle distribution (clay, silt and sand content). The third component accounted for 10.73% of total variance and showed high loading values for WSA, OM and Ks. Fig. 5 shows the projection of components 1 and 2. In this case the relationship between Ks and the variable related to water retention was lost, and WSA loading was lower than in the undisturbed soils.

The main differences between the two land use treatments are the lack of correlation between Ks and the variables related to water retention capacity in the terraced soils, which appear now in the component associated with aggregate stability, and the lack of correlation between these properties and the soil particle distribution. It is clear that the huge disturbance of the terrain for terrace construction and soil preparation is affecting typical relationships such as those existing between organic matter content and water stable aggregates and between different soil properties related to water infiltration and storage. In order to clarify the relationships between the analysed variables, a cluster analysis was performed using the same series.

Table 4
Varimax rotated principal component loading (PCi) for the four first components (terraced vineyards-disturbed soils)

	PC 1	PC 2	PC 3	Estimated communality
AWC	**0.83759**	−0.067311	0.186552	0.907907
FC	**0.94510**	0.145188	0.220059	0.962725
WP	**0.93981**	0.0610936	0.239004	0.944103
Ks	0.37590	−0241076	**0.639652**	0.608576
Clay	−0.45955	**0.67673**	0.336718	0.782536
Silt	0.06573	**0.939699**	0.13229	0.904821
Sand	0.183804	**0.805321**	−0.103026	0.692940
WSA	0.388237	0.351731	**0.518994**	0.543798
OM	0.187588	0.134453	**0.727003**	0.546959
BulkDens	−0.63791	−0.86216	0.061334	0.57665
Eigenvalue	3.89208	2.4027	1.07623	
% total variance	38.921	24.027	10.762	
% cum. variance	38.921	62.948	73.710	

AWC: available water content; FC: water retention at −33 kPa; WP: water retention at −1500 kPa; Ks: saturated hydraulic conductivity; WSA: proportion of water stable aggregates; OM: organic matter content; BulkDens: bulk density; Clay; proportion of clay; Silt: proportion of silt; Sand: proportion of sand (all values are referred to total soil mass).
Loading factors higher than 0.5 (absolute value) are shown in bold.

3.2.2. Cluster analysis

The graphical representations of the results (dendograms) obtained with the group-average method and Ward's method are presented in Figs. 6 and 7 for both undisturbed and disturbed soils. Ward's method allows higher discrimination between groups.

For the undisturbed plots, three clusters could be considered according with both Ward's method and the group-average method (Fig. 6). Both methods give similar results: one cluster grouping WSA and OM, other cluster grouping AWC, WP, FC, Ks and silt, which are in agreement with the relationship observed by the principal component analysis; and a third cluster including bulk density, clay and sand content, which are linked at higher distance than the variables included in the other two clusters. Bulk density and clay content, which appeared negatively correlated in the two first principal components, are now included in a separate group linked to the sand content.

When the same variables were analysed for the terraced vineyards (disturbed soils), cluster analysis with both methods showed a different number of clusters (Fig. 7). While according with Ward's method the analysed variables were clustered into three groups, with the group-average method four clusters should be considered, due to the large distances at which some variables are linked to the nearest cluster. According to Ward's method, there was one cluster in which a high correlation between variables was observed. This cluster grouped the variables related to water retention capacity (AWC, FC, and WP). A second cluster included Ks, WSA and OM. The third group included bulk density and clay content linked at higher distances with silt and sand content. However, using the group-average method, although AWC, FC, and WP were highly correlated, there was no clear separation between these variables and those included in the second group of Ward's

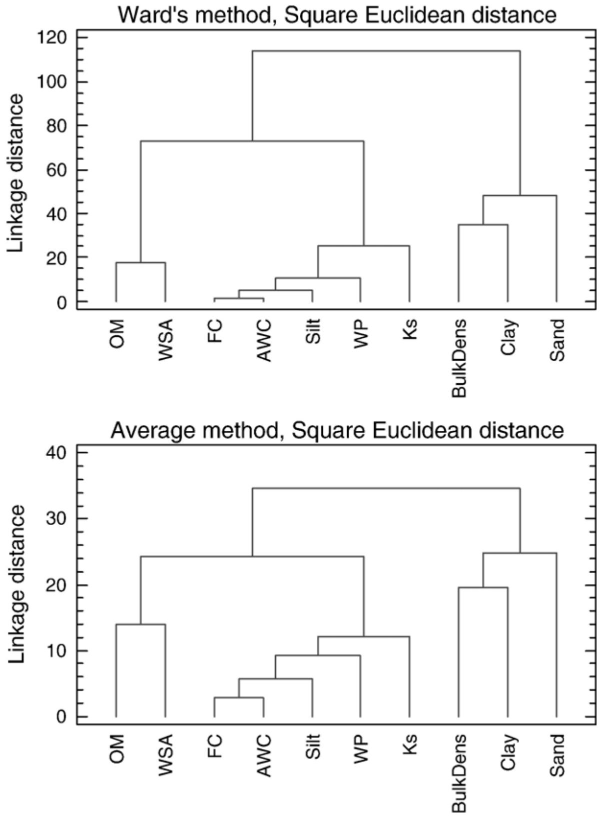

Fig. 6. Dendograms (Ward's method and average method) for the old vineyard + abandoned areas (undisturbed soils).

method, being Ks and WSA linked within this cluster at higher distances. A second cluster grouping the Clay, Silt and Sand fractions is observed. In addition, OM and Bulk density are separated into two clusters. These instabilities are in agreement with the results observed in the PC analysis, in which the increase from three to four PC separated OM in a new PC. However, while in the PC analysis with four PC retained there was difficult to explain the PC including high loading factors for WSA and Bulk density, the variable separation is now clearer. As it was argued before, the low organic matter content observed in terraced soils after removing the top horizon for terrace construction and the higher variability in the values of these properties recorded in these situations are probably the cause of these instabilities.

The combination of the different multivariate analysis techniques applied to the variables measured in different land use treatments (new terraced vineyards and traditional vineyards planted on steep slopes + abandoned areas, also without terraces) confirmed some changes in the relationship between variables. A strong correlation was observed in both cases between water retention capacity at both potentials and the available water capacity, but while on the undisturbed plots these variables were correlated with hydraulic conductivity, this was not the case in the new terraced vineyards after all multivariate analysis. In addition, the analysis confirmed that the correlation observed between aggregate stability and organic matter on the undisturbed plots disappeared on the new terraced plots due the levelling works. Instead, water stable aggregates and hydraulic conductivity seemed to show some correlation, but it was not well correlated with the organic matter content, although this correlation changes from one multivariate method to another.

Regarding the comparison of the different analysis techniques used to classify the variables, it is clear that it could be useful to use more than one method in order to extract as much information as possible. Using hierarchical clustering has the advantage of representing graphically the clustering procedure with the dendogram, which shows the combination of the variables that form the clusters and the number of clusters to be retained. It could always be useful to analyse and interpret different solutions for a different number of clusters or different numbers of components to be retained. The identification of the number of groups of variables or observations is a common problem in multivariate techniques, and it is not always satisfactorily solved using statistics (Heidam, 1982), especially in cluster techniques (Hartigan, 1985). Within the hierarchical technique, Ward's method allowed for a better interpretation of the results. However, the separation of some variables into specific clusters given by the group-average method implies the need to consider a higher number of clusters to give an interpretable solution, which in addition inform about instabilities in the relationship between variables.

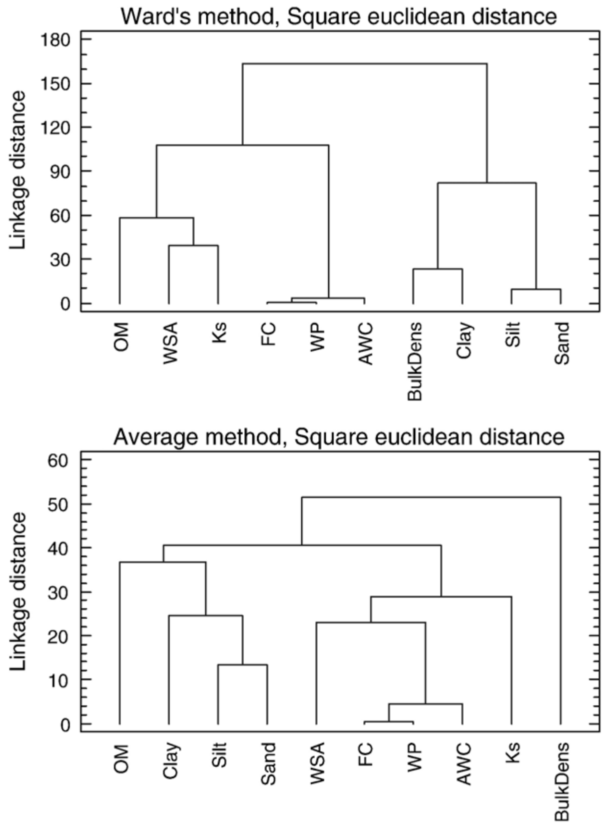

Fig. 7. Dendograms (Ward's method and average) for the terraced vineyards (disturbed soils).

4. Conclusions

Land transformations carried out in the Priorat area during the last few decades are modifying not only the landscape but also soil physical and hydrological properties, decreasing water availability to plants and saturated hydraulic conductivity. A significant reduction of up to 45% in the hydraulic conductivity and available water capacity occurs in the transformed plots. The OM content is also up to 50% lower than in undisturbed plots.

The application of the two multivariate techniques (principal component analysis and hierarchical clustering) and the different aggregation methods did not give exactly the same classification. Ward's method allowed a consistent classification with principal component analysis. Nevertheless, it is very useful to use more than one aggregation method, not only to confirm the number of clusters to be retained, but also to identify groups that could be lost if only one were used. A strong correlation was observed in both cases between water retention capacity at both potentials and the available water capacity, but while on the undisturbed plots these variables were correlated with hydraulic conductivity, this relationship was not observed in the new mechanised terraced vineyards. In addition, the strong correlation observed between aggregate stability and organic matter in the undisturbed plots is not clear on the new terraced plots. Instead, water stable aggregates and hydraulic conductivity seemed to show some correlation, but were not well correlated with the organic matter content. These facts confirm the changes taking place within the different land use scenarios analysed in relation to their physical and hydrologic soil properties.

Acknowledgements

This study work was funded by the Comision Interministerial de Ciencia y Tecnología (CICYT), Spanish Ministry of Education and Science), through the research projects REN2002-00432 and AGL2005-00091/AGR. The authors also point out the PhD grant financed by the program 'Formación de Personal Universitario' from the Ministry of Education and Science of Spain (reference AP2002-3747).

References

Abreu, X. 2005. Evaluación del efecto de las propiedades hidrológicas y sistema de manejo sobre la susceptibilidad a erosión superficial y en masa en suelos pedregosos con viña del Priorato (Cataluña, España). PhD Thesis. University of Lleida, Lleida, Spain.

Agbenin, J.O., Tiessen, H., 1995. Soil properties and their variations on two contiguous hillslopes in Northeast Brazil. Catena 24, 147–161.

Ampontuah, E.O., Robinson, J.S., Nortcliff, S., 2003. Assessment of soil particle redistribution on two contrasting cultivated hillslopes. Book of Abstracts of "Soil erosion and Sediment Redistribution in River Catchments: Measurements, Modelling and Management in the 21st Century. Silsoe, UK, p. 5.

Bartoli, F., Philippy, R., Burtin, G., 1988. Aggregation in soils with small amounts of swelling clays. I. Aggregate stability. Journal of Soil Science 39, 593–616.

Bartoli, F., Burtin, G., Royer, J.J., Gury, M., Gomendy, V., Philippy, R., Leviandier, Th., Gafrej, R., 1995. Spatial variability of topsoil characteristics within one silty soil type. Effects on clay migration. Geoderma 68, 279–300.

Bielsa, I., Pons, X., Bunce, R.G.H., 2005. Agricultural abandonment in the north eastern Iberian Peninsula: the use of basic landscape metrics to support planning. Journal of Environmental Planning and Management 48, 85–102.

Blake, G.R., Hartge, K.H., 1986. Bulk density, In: Klute, A. (Ed.), Methods of Soil Analysis, 2nd ed. Part I. Physical and Mineralogical Methods: Agronomy Monograph, vol. 9. American Society of Agronomy, Madison, WI, pp. 363–375.

Borselli, L., Torri, D., Øygarden, L., De Alba, S., Martínez-Casasnovas, J.A., Bazzoffi, P., Jakab, G., 2006. Land levelling. In: Boardman, J., Poesen, J. (Eds.), Soil erosion in Europe. John Wiley and Sons, Inc.

Busch, G., 2006. Future European agricultural landscapes—what can we learn from existing quantitative land use scenario studies? Agriculture, Ecosystems and Environment 114, 121–190.

Carpenter-Boggs, L., Kennedy, A.C., Reganold, J.P., 2000. Organic and biodynamic management: effects on soil biology. Soil Science Society America Journal 54, 1615–1659.

Chaney, K., Swift, R.S., 1984. The influence of organic matter on aggregate stability in some British soils. Journal of Soil Science 35, 223–230.

Cots-Folch, R., Martínez-Casasnovas, J.A., Ramos, C., 2006. Land terracing for new vineyard plantations in the north-eastern Spanish Mediterranean region: landscape effects of the EU council regulation policy for vineyards' restructuring. Agriculture, Ecosystems and Environment 115, 88–96.

Cousin, I., Nicoullaud, B., Coutadeur, C., 2003. Influence of rock fragments on the water retention and water percolation in a calcareous soil. Catena 53, 97–114.

De Alba, S., Lindstrom, M., Schumacher, T.E., Malo, D.D., 2004. Soil landscape evolution due to soil redistribution by tillage: a new conceptual model of soil catena evolution in agricultural landscapes. Catena 58, 77–100.

Dercon, G., Deckers, J., Govers, G., Poesen, J., Sánchez, H., Vanegas, R., Ramírez, M., Loaiza, G., 2003. Spatial variability in soil properties on slow-forming terraces in the Andes region of Ecuador. Soil and Tillage Research 72, 31–41.

Diaz, E., Roldán, A., Lax, A., Albadalejo, J., 1994. Formation of stable aggregates in degraded soil by amendment with urban refuse and peat. Geoderma 63, 277–288.

Douglas, T.D., Critchley, D., Park, G.J., 1996. The deintensification of terraced agricultural land near Trevélez, Sierra Nevada, Spain. Global Ecology and Biogeography Letters 5, 258–270.

Dutartre, Ph., Bartoli, F., Andreu, F., Porta, J.M., Ange, A., 1993. Influence of content and nature of organic matter on the structure of some sandy soils from West Africa. Geoderma 56, 459–478.

Elwell, H.A., 1986. Determination of erodibility of subtropical clay soil: a laboratory rainfed simulator experiment. Journal of Soil Science 37, 345–350.

Ferrero, A., Usowicz, B., Lipiec, J., 2005. Effects of tractor traffic on spatial variability of soil strength and water content in grass covered and cultivated sloping vineyard. Soil and Tillage Research 84, 127–138.

Figueras, A., Calvó, J., 2003. El Priorat, la vinya i el vi. Carrutxa and Centre de Promoció de la Cultura Popular i Tradicional Catalana (Departament de Cultura. Generalitat de Catalunya), p. 15.

Fonseca, F., 2006. Balance Hídrico en suelos pedregosos con viña de secano en el Priorat (Cataluña). Efectos por cambios de manejo y clima. PhD Thesis. University of Lleida. 139 pp.

García-Ruiz, J.M., Lasanta, T., Ruiz-Flaño, P., Ortigosa, L., White, S., González, C., Marti, C., 1996. Land-use changes and sustainable development in mountain areas: a case study in the Spanish Pyrenees. Landscape Ecology 11, 267–277.

Gee, G.W., Bauder, J.W., 1986. Particle size analysis. In: Black, C.A., Evans, D.D., Ensminger, L.E., White, J.L., Clark, F.E., Dinauer, R.C. (Eds.), Methods of Soil Analysis. Part I. Agronomy, vol. 9. American Society of Agronomy, Madison, WI, pp. 393–411.

Hanson, C.T., Blevins, R.L., 1979. Soil water in coarse fragments. Soil Science Society of America Journal 43, 819–820.

Hartigan, J.A., 1985. Statistical theory in clustering. Journal of Classification 2, 63–76.

Heidam, N.Z., 1982. Atmospheric aerosol, factor models, mass and missing data. Atmospheric Environment 16, 1923–1931.

Iglésies, J., 1975. Les minves dels cultius i de la població a la comarca del Priorat, vol. 29. Fundació Salvador Vives Casajuana, Madrid (Spain).

Janeau, J.L., Bricquet, J.P., Planchon, O., Valentin, C., 2003. Soil crusting and infiltration on steep slopes in northern Thailand. European Journal of Soil Science 54, 543–554.

Kaiser, H.F., Rice, J., 1974. Little jiffy, mark IV. Educational and Psychological Measurement 34, 111–117.

Kemper, W.D., Rosenau, R.C., 1986. Aggregate stability and size distribution, In: Klute, A. (Ed.), Methods of Soil Analysis. Part I, Physical and Mineralogical Methods, 2nd edition. Agronomy, vol. 9. American Society of Agronomy, Madison, WI, pp. 425–442.

Léonard, J., Andrieux, P., 1998. Infiltration characteristics of soils in Mediterranean vineyards in southern France. Catena 32, 209–223.

León-González, F., Hernández-Serrano, M.M., Etchevers, J.D., Payán-Zelaya, F., Ordaz-Chaparro, V., 2000. Short-term effect on macroaggregation in a sandy soil under low rainfall in the Valley of Mexico. Soil and Tillage Research 56, 213–217.

Lundekvam, H.E., Romstad, E., Øygarden, L., 2003. Agricultural policies in Norway and effects on soil erosion. Environmental Science & Policy 6, 57–67.

Malet, J.P., Auzet, A.V., Maquaire, O., Ambroise, B., Descroix, L., Esteves, M., Vandervaere, J.P., Truchet, E., 2003. Soil surface characteristics influence on infiltration in black marls: application to the Super-Sauze earthflow (southern Alps, France). Earth Surface Processes and Landforms 28, 547–564.

Martínez-Casasnovas, J.A., Sánchez-Bosch, I., 2000. Impact assessment of changes in land use/conservation practices on soil erosion in the Penedès-Anoia vineyard region (NE Spain). Soil and Tillage Research 57, 101–106.

Massart, D.L., Kaufman, L., 1983. The Interpretation of Analytical Chemical Data by the Use of Cluster Analysis. John Wiley & Sons, Inc., New York.

Milligan, G.W., 1980. An examination of the effect of six types of error perturbation on fifteen clustering algorithms. Psychometrika 45, 325–342.

Nelson, D.W., Sommers, L.E., 1982. Total carbon, organic carbon and organic matter, In: Page, A.L., et al. (Eds.), Methods of Soil Analysis. Part 2. Chemical and Microbiological Properties, 2nd ed. Agronomy, vol. 9. American Society of Agronomy. Madison, Madison, WI, pp. 539–577.

Nyamangara, J., Gotosa, J., Mpofu, S.E., 2001. Cattle manure effects on structural stability and water retention capacity of a granitic sandy soil in Zimbabwe. Soil and Tillage Research 62, 157–162.

Ouédraogo, E., Mando, A.M., Zombré, N.P., 2001. Use of compost to improve soil properties and crop productivity under low input agricultural system in West Africa. Agriculture, Ecosystems and Environment 84, 259–266.

Perroux, K.M., White, I., 1998. Designs for disc permeameters. Soil Science Society of America Journal 52, 1205–1215.

Pla, I., 1983. Metodología para la caracterización física con fines de diagnóstico de problemas de manejo y conservación de los suelos en condiciones tropicales. Alcance 32. Revista de la Facultad de Agronomia, vol. 34. Universidad Central de Venezuela. Maracay, Venezuela. 91 pp.

Pla, I., Nacci, S., 2003. Traditional compared to new systems for land management in vineyards of Catalonia (Spain). In: Roose, E., Sabir, M., De Noni, G. (Eds.), Techniques Traditionnelles de GCES en milieu mèditerranien. Bulletin Reseau Erosion, vol. 21, pp. 213–223. Montpellier (France).

Poesen, J., Lavee, H., 1994. Rock fragments in top soils: significance and processes. Catena 23, 1–28.

Poesen, J.W., Ingelmo-Sánchez, F., Mücher, H., 1990. The hydrological response of soil surfaces to rainfall as affected by cover, position and rock fragments in the top layer. Earth Surfaces Processes and Landforms 16, 653–671.

Porta, J., López-Acevedo, M., Roquero, C., 1999. Edafología para la agricultura y el medio ambiente. Mundi-Prensa, Madrid. 849 pp.

Priorat QDO, 2005. http://www.doqpriorat.org/. Last accessed: 01/05/2006.

Sauer, T.J., Logsdon, S.D., 2002. Hydraulic and physical properties of stony soils in a small catchment. Soil Science Soiety of America Journal 66, 1947–1956.

Sevink, K., Vertraten, J.M., Jongejans, J., 1998. The relevance of humus forms for land degradation in Mediterranena mountainous areas. Geomorphology 23, 285–292.

Soil Survey Staff, 1999. Keys to soil taxonomy. 8th edition. U.S. Department of Agriculture — Soil Conservation Service. Washington, D.C.

Tisdall, J.M., Oades, J.M., 1982. Organic matter and water stable aggregates in soils. Journal of Soil Science 33, 141–163.

Thapa, B.B., Cassel, D.K., Garrity, D.P., 1999. Assessment of tillage erosion rates on steepland oxisols in the humid tropics using granite rocks. Soil and Tillage Research 51, 233–243.

Torri, D., Borselli, L., Calzolari, C., Yañez, M., Salvador-Sanchis, M.P., 2002. Soil erosion, land use, soil quality and soil functions: effects of erosion. In: Rubio, J.L., Morgan, R.P.C., Asins, S., Andreu, V. (Eds.), Man and Soil at the Third Millennium. Geoforma Ediciones-CIDE, Logroño, Spain, pp. 131–148.

Turkelboom, F., Ongprasert, S., Taejajai, U., 1996. Soil fertility dynamics in steep land alley farming. In: Sajjapongse, A. (Ed.), Proceedings of the Seventh Annual Meeting on the Management of Sloping Lands for Sustainable Agriculture in Asia, DLD and IBSRAM, Chiang Mai, Thailand, October 16–20, 1995.

Turkelboom, F., Poesen, J., Ohler, I., Van Keer, K., Ongprassert, S., Vlassak, K., 1997. Assessment of tillage erosion rates on steep slopes in northern Thailand. Catena 29, 29–44.

Van Muysen, W., Govers, G., Bergkamp, G., Roxo, M., Poesen, J., 1999. Measurement and modelling of the effects of initial soil conditions and slope gradient on soil translocation by tillage. Soil and Tillage Research 51, 303–316.

Zalidis, G., Stamatiadis, S., Takavakoglou, V., Eskridge, K., Misopolinos, N., 2002. Impacts of agricultural practices on soil and water quality in the Mediterranean region and proposed assessment methodology. Agriculture, Ecosystems and Environment 88, 137–146.