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Soil alteration due to erosion, ploughing and levelling of vineyards in north east Spain

Short title: **Soil alteration in vineyards in north east Spain**

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Abstract

Since the 1970s and 1980s, the vineyard areas in the Mediterranean region of north east Spain have undergone profound transformation to allow greater mechanization. This has involved land levelling, deep ploughing and the elimination of traditional soil conservation measures. At present the EU Common Agricultural Policy encourages this through the vineyard restructuring and conversion plans (Commission Regulation EC No 1227/2000 of 31 May 2000) by subsidizing up to 50% of the cost of soil preparation such as soil movement and land levelling. A clear example of the problems that this causes is in the Penedès vineyard region (Catalonia, north east Spain), and the present research analyzes the changes in soil properties caused by erosion, deep ploughing and land levelling. The study was carried out in an area of 30 000 ha for which a soil information system at a scale of 1:50 000 was developed based on 394 field observations (89 soil profiles and 251 auger hole samples down to 120 cm). The results show that 74% of the described soil profiles are disturbed with evidence of soil mixing and/or profile truncation due to erosion, deep ploughing and/or land levelling. The evidence from the topsoils consists mainly of fragments of calcic or petrocalcic horizons, marls and sandstones. Other important properties for crops such as organic matter content and soil depth show statistically significant differences between disturbed soils and undisturbed soils (22.3–33.3% organic matter content depletion and 35.1% soil depth reduction). These results confirm that the soils of the region are significantly altered by mechanical operations which also influence soil erosion and contribute to the global warming effect through depletion of soil organic matter.

Key-words: soil erosion, ploughing, land levelling, crop mechanization, Mediterranean region, Spain

Introduction

Soil degradation is the loss of soil's capacity to perform its functions (Blum, 1993) and results in a decline in soil quality. It is a biophysical process affecting physical, chemical and biological properties and is caused by erosion, improper agricultural practices, machinery, inappropriate or excessive tillage, overgrazing or industrial activities; it can be exacerbated by socio-economic and political factors (Lal, 2001; Poch and Martínez-Casasnovas, 2002).

Among the intrinsic processes causing land degradation, erosion is the most widespread and is widely studied. Many researchers have quantified soil loss in different environments (e.g. Martínez-Casasnovas *et al.*, 2002; Martínez-Casasnovas, 2003), analyzed biophysical influencing factors and predicted or modelled soil losses (Wischmeier and Smith, 1978; Renard *et al.*, 1996; Laflen *et al.*, 1997; Morgan, 2001), and determined the effects on crop productivity (Lal, 2001), nutrient losses and infrastructures (Martínez-Casasnovas *et al.*, 2005, Martínez-Casasnovas and Ramos, 2006) and, most recently, the greenhouse effect (Lal, 2003, 2005). Other studies have measured the changes in soil properties resulting from these processes, mainly focusing on quantifying the depletion of organic matter content, the reduction of soil depth, changes in bulk density, infiltration capacity and moisture retention (Ebeid *et al.*, 1995; Fullen and Brandsma, 1995; Fenton *et al.*, 2005).

An assessment of soil profile truncation has been one of the traditional approaches for quantifying change in soil properties caused by erosion (Lowrance *et al.*, 1988; Phillips *et al.*, 1999). Several researchers have criticized this method in absolute terms since (a) it is difficult to find uneroded reference soil profiles in agricultural areas, (b) deep ploughing can mix soil layers and mask the effects of erosion and (c) there may be natural local-scale variability in soil thickness (Phillips *et al.*, 1999). In addition, profile truncation can result from past erosion and it is not possible to determine whether the erosion processes are still active. Nevertheless, in comparison with other methods such as determination of reservoir sedimentation and estimation using the Revised Universal Soil Loss Equation (RUSLE), the estimates of soil alteration due to erosion based on measuring the degree of profile truncation have produced convergent results (Kreznor *et al.*, 1992; Phillips *et al.*, 1999). Soil profile truncation has also been used as a reference for validating other soil loss prediction methods (e.g. ^{137}Cs derived soil erosion rates, Van Oost *et al.*, 2005), for reconstructing sediment budgets in catchments (Rommens *et al.*, 2005), and for developing new models of soil catenary evolution in agricultural landscapes (De Alba *et al.*, 2004). The latter arise from the growing recognition that tillage erosion plays an important role in the redistribution of soil on agricultural land and causes soil profile truncation and/or accretion (Schumacher *et al.*, 1999; Nyssen *et al.*, 2000; Van Oost *et al.*, 2005; Peeters *et al.*, 2006).

Although water erosion is the most widespread cause of soil profile change, there are other intrinsic processes (e.g. levelling and deep ploughing) as well as extrinsic causes (e.g. inadequate agricultural policies) that can significantly contribute to the degradation or alteration of soil properties (Lundekvam *et al.*, 2003; Borselli *et al.*, 2006; Cots-Folch *et al.*, 2006). Land levelling and terracing are important in European agriculture, but associated problems and impacts have not been widely studied (Cots-Folch *et al.*, 2006). Nevertheless, some authors have reported the effects of these operations on soil properties. For example, in vineyards in north east Spain (Penedès, Catalonia), extensive land levelling to reduce slope gradient and increase field size to permit mechanisation has occurred in the last few decades leading to a 26.5% increase in average annual soil loss (Jiménez-Delgado *et al.*, 2004).

Results from other research in this region has shown that land levelling before vineyard establishment led to major differences in soil depth ranging from 50 to 110 cm and in soil characteristics (Ramos and Martínez-Casasnovas, 2006a). The result is variability in soil moisture at the same depth in different localities which has impacts on yield (16-50% less in levelled areas). Since 2000 the EU Common Agricultural Policy, through the vineyard restructuring and conversion plans (Commission Regulation EC No 1227/2000 of 31 May 2000), subsidizes by up to 50% of the cost of soil preparation such as soil movement and land levelling. The Penedès vineyard region in Catalonia, north east Spain, provides a clear example of the soil consequences from such processes. It is a traditional area for vineyards producing high quality wine. The region has frequent high-intensity rainfall events (>80 mm h^{-1}) and soil parent materials of unconsolidated Tertiary calcilutites and sandstones that are highly susceptible to erosion (Martínez-Casasnovas et al., 2005). In this study we examine the change in soil properties due to the combined effects of erosion, land levelling and deep ploughing. This is done by investigating profile truncation or alteration in 89 soil profiles in an area of 30 000 ha. We do not attempt to provide an absolute estimate of soil loss due to profile truncation or alteration but rather an evaluation of the changes from the combined effects of erosion, extensive land levelling and deep ploughing.

Material and methods

Study area

The study area of 30 000 ha in the Penedès region, Catalonia, north east Spain is about 30 km south west of Barcelona, between the Sierra Prelitoral mountains and the Anoia and Llobregat rivers (Figure 1). Vineyards occupy 35% of the area and winter cereals which alternate with vineyards cover 6%. Other important land uses are grassland and shrubland (25%) and forested shrubland (17%), mainly in gullies and steeply sloping areas that were abandoned from agriculture. Other minority crops include almond, olive and peach plantations. The area is part of the Penedès Tertiary Depression where calcilutites (marls) and occasional sandstones and conglomerates outcrop. The landscape is dissected by a dense and deep network of gullies. Inter-gully areas are usually undulating to rolling, with an average slope of 10-15%.

The climate is Mediterranean with a mean annual temperature of 15 ºC and a mean annual rainfall of 550 mm (Ramos and Porta, 1994). Rainfall mainly occurs in two periods: September to November, with frequent high-intensity rainstorms (e.g. >100 mm h^{-1} in 5-min periods), and in April to June. The rainfall erosivity factor (R) ranges from 1049 to 1200 MJ mm ha^{-1} h^{-1} yr^{-1} (Ramos, 2002). Deep ploughing <0.6-0.7 m before the established of vines is common to encourage root penetration and plant establishment (Figure 2a). Recently, land levelling has been widely used to create larger and more easily-managed fields, a practice that involves the abandoning of traditional soil conservation measures and the alteration of soil profiles (Figure 2b). Soil change results from 2-5 m of excavation (Ramos and Martínez-Casasnovas, 2006a), leading to the exposure of underlying marls, sandstones and conglomerates (Figure 4). Jiménez-Delgado *et al.* (2004) report a 26.5% increase in average annual soil loss associated with these land transformations with the removal of the traditional broad terraces. These terraces, locally named *rases*, have eight to ten rows of vines which intercept runoff and direct it out of the field via lateral dirt tracks which act as drainage channels. In addition, the terraces act as sediment traps, capturing about 54% of the sediments generated during high-intensity rainfalls (Martínez-Casasnovas *et al.*, 2005). It is therefore important to retain these conservation practices in new plantations and to maintain those in existing plantations rather than to eliminate them in favour of vineyard mechanization.

[INSERT FIGURE 1 ABOUT HERE]

[INSERT FIGURE 2 ABOUT HERE]

Soil information system

The analysis of soil alteration by erosion, levelling and deep ploughing in the study area used a Soil Information System (SIS) based on a Geographical Information System (GIS) and associated soil database. The SIS contains at 1:50 000 spatial and descriptive data from a soil survey for the study area. To achieve this, 394 field observations (89 soil profiles and 251 auger holes down to 120 cm), were described according to the SINEDARES (CBDSA, 1983) and CatSIS (Boixadera *et al.*, 1989) description systems. The sample density was 1.31 observations per 100 ha. Soils were classified according to Soil Taxonomy to the family level (Soil Survey Staff, 1999, 2006).

Analysis of the degree of soil property alteration

The degree of soil alteration due to the combined effects of erosion, levelling and deep ploughing was determined from analysis of the field descriptions and laboratory analysis from 89 soil profiles stored in the SIS. Two main aspects were considered: (1) quantification of and type of mixing in the topsoil layers and (2) comparison with reference to soils with and without mixing.

The cause of mixing in the studied soils is difficult to determine because the possible causes of erosion, levelling and deep ploughing often have similar effects. Erosion processes result in the progressive loss of the upper, most fertile soil layer, reduction in soil depth and mixing of materials from different horizons after ploughing. This can result in topsoils with different properties (e.g. less organic matter, more calcium carbonate, more coarse material and different texture). With erosion, underlying horizons can be completely incorporated or the parent material can be exposed. The presence of rills or gullies in the area near to the profile that is being evaluated can help to determine the cause of layer mixing or profile truncation. Nevertheless, in the study area this can lead to errors because of elimination of weeds which masks evidence of erosion (Martínez-Casasnovas *et al.*, 2002).

Because vineyards have been cultivated in this region since the Middle Ages, and deep ploughing and land levelling have recently been done, it was difficult to find undisturbed plots that could provide information on original soil conditions. Thus we determined the degree of alteration of soils by looking at the evidence for disturbance in the topsoil layers, such as fragments of calcic or petrocalcic horizons or the presence of coarse particles of Tertiary materials (calcilutites, sandstones or unconsolidated conglomerates).

The analysis was carried out by querying the soil database in the SIS. Queries were formed by means of Structured Query Language (SQL) using the Microsoft Access 2002 database management system. The results from the queries allowed comparison of selected soil properties with and without evidence of disturbance and were analyzed by statistical tests of independence (Student's *t*-test and Pearson's chi-square test) (Everitt, 1977; Hays, 1988). In the case of Pearson's chi-square tests, expected frequencies <5 in contingence tables of more than one degree of freedom were accepted if they corresponded to <10% of the events. Where there was only one degree of freedom (2x2 contingence tables) and with expected frequencies below 10, the Yates' correction for continuity was applied (Everitt, 1977).

Results and discussion

Soils of the study area

Through using Soil Taxonomy (Soil Survey Staff, 1999, 2006), the 89 soil profiles described in the study area belong to 22 different soil families (Table 1 which also includes the tentative classification of the other 251 field observations [auger hole samples down to 120 cm] in the Soil Information System).

[INSERT TABLE 1 ABOUT HERE]

From Table 1, the two most extensive soil subgroups described in the Penedès study area are Typic Calcixerepts (39.1% of the observations) and Typic Xerorthents (22.6%). Petrocalcic Calcixerepts (17.3%) and Fluventic Haploxerepts (9.1%), with calcic endopedons are also common. The high proportion of carbonate enriched soils (22% of soil profiles and 19% of other field observations) indicates the intensity of calcification. Less frequently occurring families are the Aquic Haploxerepts (0.6%) and the Typic Haploxerepts (1.5%), the former being specifically associated with areas of deficient drainage and the latter with non-calcareous parent materials of schists.

Many of the soils display evidence of topsoil truncation. For example, in numerous cases the ochric epipedon has been replaced by the underlying calcilutites which now forms the arable horizon. In other cases, the top layer has evidence of mixing with the underlying calcic horizon with calcium carbonate contents ca. 50% (Figure 3). Vines planted on these soils show poor development because of ferric chlorosis problems. This indicates an inflection point in soil development in accordance with current denudation dynamics (Martínez-Casasnovas, 1998) or human-induced processes such as deep ploughing and land levelling. Nevertheless, field observations of the incision rills and gullies after very intense rainstorms confirm current erosion activity (Martínez-Casasnovas *et al.*, 2002, 2005).

[INSERT FIGURE 3 ABOUT HERE]

Degree of soil property alteration due to erosion, levelling and deep ploughing

Evidence of layer mixing. Evidence for mixing of the upper soil horizons was found in 66 (74%) out of the 89 analyzed profiles (Table 2). The evidence for mixing was the presence of calcic or petrocalcic horizons in 56% of the profiles with associated evidence of disturbance, and shallow soils with calcilutites, sandstones or conglomerates as underlying material in 29% of these profiles. In 9% the disturbance was clearly caused by soil translocation as a result of levelling. In these cases coarse fragments of calcilutites or sandstones were found in the topsoil layer from the levelling (Figure 4). The remaining 6% of the evidence was expressed in the presence of fragments of Bw, Bt or C horizons. It was not possible to distinguish mixing of horizons by ploughing from other processes. Nevertheless, there was clear evidence of mixing in soils which had been ploughed to a depth > 0.50 m.

[INSERT TABLE 2 ABOUT HERE]

[INSERT FIGURE 4 ABOUT HERE]

Effects on organic matter content. The combined effects of mixing the top layers with underlying material by erosion and levelling has important effects on soil properties. Although the average organic matter (OM) content of the topsoil in undisturbed soils was low (1.17±0.57%, n=17), significantly lower OM contents were found in soils showing evidence of disturbance (0.91±0.56%, n=31, $P<0.05$). The organic matter content of shallow soils with a maximum depth of 0.30 m was found to be even lower (0.78±0.24%, n=12, $P<0.05$). In these shallow soils, the evidence of disturbance in the topsoil layer could only be due to erosion and not to deep ploughing because it is not possible to plough more than 0.30 m. These results agree with other research that shows that erosion significantly reduces soil organic content in cultivated soils (Nizeyimana and Olson, 1988; Ebeid *et al.*, 1995). The degree of erosion of the soils in the Penedès area can be considered as moderate on the basis of a 22-33% reduction in the OM content which compares with a 20-35% reduction in OM content in till-derived soils devoted to corn in Iowa (Fenton *et al.*, 2005), and in loamy sand soils of Shropshire, UK (Fullen, 1995). This reduction in OM is not compensated by the application of cattle manure before vineyard establishment at a rate of 30-40 Mg ha^{-1} though some viticulturists have encouraged the application of cattle manure or organic wastes every

3-4 years at rates of 30-50 Mg ha^{-1} to improve soil structure and water infiltration (Martínez-Casasnovas and Ramos, 2006; Ramos and Martínez-Casasnovas, 2006).

Effects on calcium carbonate content. An increasing trend was observed in the calcium carbonate content for disturbed topsoils of soils compared to undisturbed ones although there are no statistically significant differences. The mean content of the top horizons without evidence of mixing is 30.8±8.2% (n=14) compared with 34.0±12% (P=0.199, n=33). This is probably due to the natural high calcium carbonate content of the parent materials since 67.8% of the 28 parent material samples had calcium carbonate contents >20%, with a maximum of 53.9%. The differences in calcium carbonate content between disturbed and undisturbed soils increases if shallow soils with evidence of disturbance (maximum tilling depth of 0.30 m) are separately considered. In this case the mean calcium carbonate content is 36.7±9.4% (P=0.051, n=12), which seems to indicate a greater influence of erosion than deep ploughing as the process responsible for the carbonate enrichment in these soils.

Calcium carbonate enrichment of topsoil has consequences on vine development and yield (Figure 5) because it causes iron deficiency (Mengel *et al.*, 1984). This is commonly observed in vines on calcareous soils as observed by Reyes *et al.* (2006) in a study relating the incidence of Fe chlorosis in vines of southern Spain to inherent soil properties. Lindstrom *et al.* (1986) stress the need for higher application rates of fertilizers to compensate for the increase in calcium carbonate content in agricultural soils due to land levelling.

[INSERT FIGURE 5 ABOUT HERE]

Effects on soil structure. From the analysis comparing the structure of the horizons with and without evidence of mixing (Table 3), there are no significant differences in the type of structure, the degree of structure development, the size of the aggregates, or the presence of secondary structure (P>0.05). This can be explained by intensive farming of these vineyard soils for eliminating weeds which must have modified the original soil structure (Martínez-Casasnovas and Ramos, 2006). Ramos *et al.* (2003) through investigating 11 reference soils in the same area analyzed the effects of raindrop impact on aggregate stability. Their results confirm that in general the soils are unstable to slaking and to mechanical disturbance. The less stable soils have a high silt content which also encourages crust formation.

Land levelling can have a negative influence on soil structure as shown by Lundekvam *et al.* (2003) who confirm very adverse effects of land levelling on soil structure and erodibility. In the same study area as the present one, Ramos and Martínez-Casasnovas (2006b) also report that cultivated soils after land levelling are very low in organic matter and are highly susceptible to erosion with most precipitation lost as runoff. A possible solution to improve soil structure that has been recently tested by Ramos and Martínez-Casasnovas (2006b) by the application of compost from cattle manure and they showed that this is an important source of N and P besides other nutrients and can also increase infiltration rates by up to 26%. However, due to the high susceptibility of these soils to crusting, erosion rates are relatively high, so a higher nutrient concentration on the soil surface increases non-point pollution.

[INSERT TABLE 3 ABOUT HERE]

Effects on soil depth. There are significant differences (P<0.01) in effective soil depth as a result of disturbance. These soils have an average depth of 0.83±0.4 m (n=59) compared with 1.28±0.5 m (n=24) for soils without evidence of mixing. This indicates a progressive reduction in effective depth by the combined effects of erosion and/or soil translocation due to levelling. These results accord with those of Ramos and Martínez-Casasnovas (2006a) who found cuttings <2.5 m from levelling resulting in soils <0.6 m deep. In contrast to deeper soils, these soils have lower moisture contents of up to 5% in the surface layer and a reduction in yield of 16-50% depending on vine variety. The land levelling and deep ploughing effects as described in this paper add to those reported in other studies in the Penedès region. Table 4 summarizes reported on-site land levelling effects, indicating the local magnitude and possible consequences which highlight the impact of these land transformations on soil properties and crop production.

[INSERT TABLE 4 ABOUT HERE]

Conclusions

The Soil Information System at a 1:50 000 scale for the Penedès vineyard region of 30 000 ha provides information on the degree of soil alteration based on organic matter and calcium carbonate content, soil structure and soil depth. These were assessed by comparing these properties between disturbed and undisturbed soils. The most abundant soils in the area are Typic Calcixerepts and Typic Xerorthents. Fluventic Haploxerepts with a calcic endopedon; Petrocalcic Calcixerepts are also frequent. The abundance of soils with evidence of secondary accumulation of calcium carbonate reflects the calcium richness of the parent materials (mainly calcilutites with calcium carbonate contents of 30-50% and limestone gravels).

Analysis of the soil information confirms that soils of the study area suffer intense erosion and/or anthropogenic transformation (land levelling and deep ploughing) which lead to the progressive loss of soil material, a reduction in organic matter content and effective soil depth, calcium carbonate enrichment of arable layers and degradation of soil structure. This study was not able to identify the particular processes responsible for the degradation, except for the evidence for levelling close to the described profiles.

At present soil preparation, stone clearance and land levelling are subsidized by the EU through vineyard restructuring and conversion regulations (Commission Regulation EC No. 1227/2000 of 31 May 2000). The main objective of these is to modify production to market demand. However, the present research suggests that land levelling and the resultant increase in erosion alter soil properties and could contribute to global warming by depleting soil organic matter.

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Figure captions

Figure 1. Location of the study area and the spatial distribution of the 89 investigated reference soil profiles. The symbols in the soil profiles refer to different sampled landscape areas as identified by Martínez-Casasnovas (1998): A) Mountain, B) Piedmont, C) High dissected valley-glacis, D) Low dissected valley-glacis, E) River valleys.

Figure 2. a) Deep ploughing to 0.6-0.7 m prior to vine planting. The white colour of the soil indicates the mixing of the original A horizon with the underlying calcic horizon. b) Land levelling in the Penedès region to for mechanization in the vineyard.

Figure 3. Example of soil with evidence of layer mixing (Typic Calcixerept, coarse-loamy, carbonatic, thermic). Detail of rhizoconcretions of calcium carbonate on surface. (The scale bar indicates 1 cm per division).

Figure 4. Example of topsoil as a result of levelling. On the surface there are fragments of the underlying materials (calcilutites and sandstones). In the background, the mound on the hill shows the land morphology prior to levelling. A 2.5 m layer of soil material was cut here to level the field.

Figure 5. Differences in plant development due to calcium carbonate enrichment of the topsoil in a vineyard in the Penedès region.

Table 1. Families of described soils in the Penedès vineyard region according to Soil Taxonomy (Soil Survey Staff, 1999, 2006).

Family	Number of soil profiles	Number of other field observations
Petrocalcic Palexeralf, fine, mixed, thermic	2	0
Calcic Haploxeralf, fine-loamy, carbonatic, thermic	1	4
Typic Haploxeralf, loamy-skeletal, mixed (calcareous), thermic	1	3
Petrocalcic Calcixerept, coarse-loamy, mixed, thermic	2	13
Petrocalcic Calcixerept, loamy, mixed, thermic, shallow	5	39
Typic Calcixerept, fine-loamy, mixed, thermic	9	25
Typic Calcixerept, sandy-skeletal, carbonatic, thermic	4	16
Typic Calcixerept, loamy-skeletal, mixed, thermic	1	2
Typic Calcixerept, coarse-silty, carbonatic, thermic	4	2
Typic Calcixerept, sandy, mixed, thermic	2	6
Typic Calcixerept, coarse-loamy, mixed, thermic	7	20
Typic Calcixerept, fine-silty, carbonatic, thermic	4	18
Typic Calcixerept, coarse-loamy, carbonatic, thermic	6	7
Fluventic Haploxerept, fine-loamy, mixed (calcareous), thermic	7	24
Typic Haploxerept, coarse-loamy, mixed (calcareous), thermic	2	3
Aquic Haploxerept, coarse-loamy, mixed (calcareous), thermic	1	1
Typic Xerofluvent, fine-silty, mixed (calcareous), thermic	6	9
Typic Xerofluvent, coarse-loamy, mixed (calcareous), thermic	5	10
Typic Xerorthent, silty, mixed (calcareous), thermic, shallow	7	5
Typic Xerorthent, loamy, mixed (calcareous), thermic, shallow	11	39
Lithic Xerorthent, loamy, mixed (non acid), thermic, shallow	1	4
Lithic Xerorthent, loamy, mixed (calcareous), thermic, shallow	1	1

Table 2. Evidence of disturbance in topsoil horizons in the reference profiles described in the Penedès vineyard region.

Type of evidence	Number of reference soil profiles
Fragments of calcilutites or sandstones	15
Fragments of petrocalcic horizon	5
High frequency of coarse material (gravels from unconsolidated Tertiary conglomerates)	4
$CaCO_3$ nodules	17
Rhizoconcretions of calcium carbonate	15
Fragments of Bw or C horizons	3
Fragments of Bt horizons	1
Levelling	6
Total number of profiles with evidence of disturbance	66

Table 3. Results from chi-square tests on frequency data for soil structure type and evidence of mixing.

Structure type	Soil profiles with evidence of mixing		Soil profiles with no evidence of mixing	
	Observed	Expected	Observed	Expected
Subangular blocks (weak or very weak)	30	29	10	11
Subangular blocks (moderate or strong)	24	24.6	10	9.3
Compound granular	4	2.9	2	1.7

p-value= 0.718 (Pearsons' chi-square test)

Aggregate size	Soil profiles with evidence of mixing		Soil profiles with no evidence of mixing	
	Observed	Expected	Observed	Expected
Fine	6	5.8	2	2.2
Medium	26	25.4	9	9.6
Coarse	26	26.8	11	10.2

P= 0.921 (Pearsons' chi-square test)

Secondary structure	Soil profiles with evidence of mixing		Soil profiles with no evidence of mixing	
	Observed	Expected	Observed	Expected
Without secondary structure	38	39.9	17	15.1
With secondary structure	20	18.1	5	6.9

P= 0.449 (Yates' Chi-Square test)

Table 4. Levelling effects in the Penedès vineyard region.

Land levelling effect	***Local magnitude***	***References***
Land cutting and filling	<5 m <2.5 m	Jiménez-Delgado *et al.* (2004) Ramos and Martínez-Casasnovas (2006a)
Elimination of existing conservation measures (broad-based terraces)	26.5% increase in average annual soil loss	Jiménez-Delgado *et al.* (2004)
Soil mixing	74% of the analyzed soil profiles show evidence of layer mixing	this study
Organic matter depletion	22-33%	this study
Enrichment of calcium carbonate content of topsoil	up to 10.4% increase	this study
Reduction in soil depth	up to 54% reduction	this work
Reduction in soil water content	<20% in highly disturbed soils	Ramos and Martínez-Casasnovas (2007)
Susceptibility to soil sealing	minimum hydraulic conductivity of the seal 3-6 mm h^{-1} in highly disturbed soils comparedwith 40 mm h^{-1} in less disturbed soils	Ramos and Martínez-Casasnovas (2007)
Reduction in water retention capacity	8.0-11.2% at −1500 kPa, 18.3-21.3% at −33 kPa in highly disturbed soils compared with 13% at −1500 kPa and 31-36% at −33 kPa in less disturbed soils	Ramos and Martínez-Casasnovas (2006a) Ramos and Martínez-Casasnovas (2007)
Increase in sediment yield from levelled vineyard fields	higher sediment concentration in disturbed soils (9 compared with 5 g L^{-1})	Ramos and Martínez-Casasnovas (2006a) Ramos and Martínez-Casasnovas (2007)

Reduction in crop yield	Crop yield decreased depending on the degree of land levelling	Ramos and Martínez-Casasnovas (2006a)

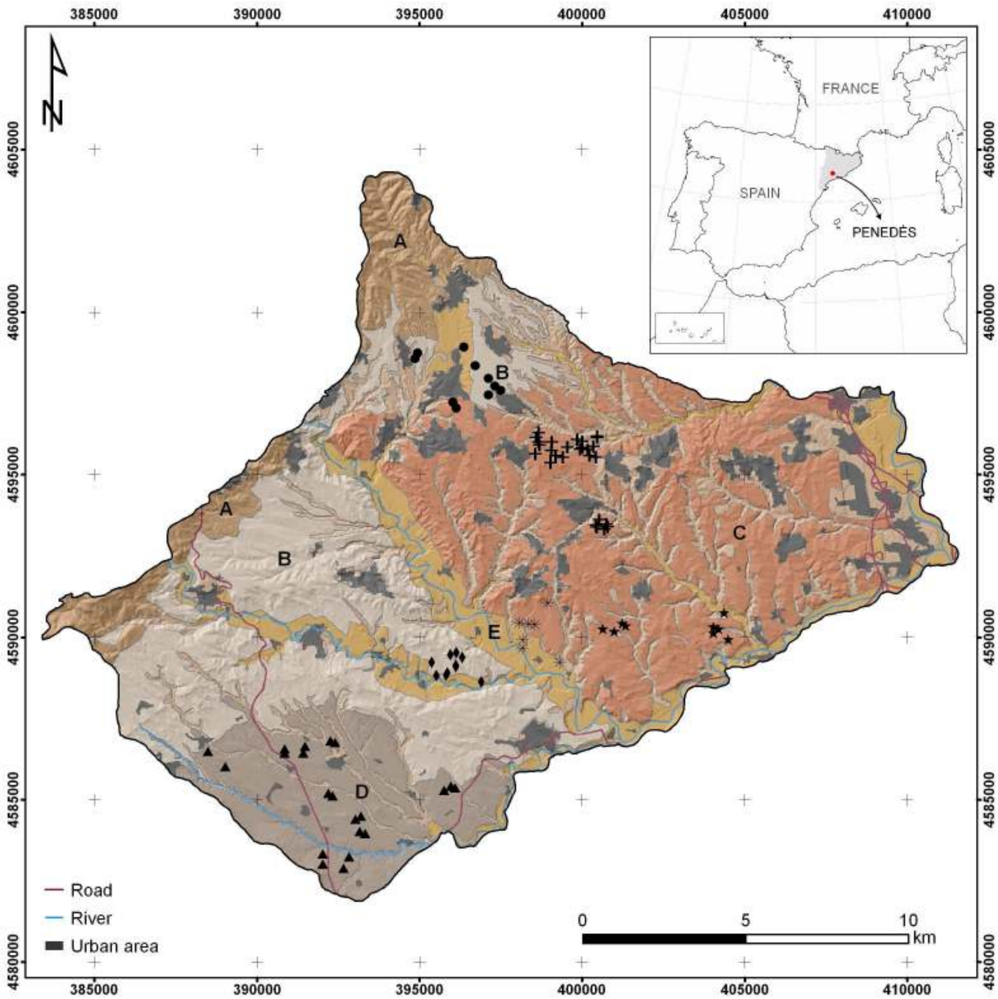

Figure 1. Location of the study area and the spatial distribution of 89 reference soil profiles described and analyzed in this paper. The symbols of the soil profiles refer to different sample landscape areas identified by Martínez-Casasnovas (1998): A) Mountain, B) Piedmont, C) High dissected valley-glacis, D) Low dissected valley-glacis, E) River valleys.
199x199mm (300 x 300 DPI)

Figure 2. a) Deep ploughing, up to 0.6-0.7 m, prior to vine planting. The white colour of the soil indicates the mixing of the original A horizon with the underlying calcic horizon.
22x14mm (600 x 600 DPI)

Figure 2. b) Land levelling in the Penedès region to adapt vineyard to mechanization.
22x14mm (600 x 600 DPI)

Figure 3. Example of soil with evidence of layer mixing (Typic Calcixerept, coarse-loamy, carbonatic, thermic). Detail of rhizoconcretions of calcium carbonate on surface. (The scale bar indicates 1 cm per division).
150x99mm (360 x 360 DPI)

Figure 4. Example of topsoil as a result of levelling. On the surface, fragments of the underlying materials (calcilutites and sandstones). In the background, the mound on the hill shows the land morphology prior to levelling. A 2.5 m layer of soil material was cut here to level the field.
100x65mm (599 x 599 DPI)

Figure 5. Differences in plant development due to calcium carbonate enrichment of the topsoil in a vineyard field of the Penedès region.
22x14mm (600 x 600 DPI)