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

J. A. Martínez-Casasnovas & M. Concepción Ramos
Department of Environment and Soil Science, University of Lleida, Rovira Roure 191, 25198 Lleida, Spain

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. Recently 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 Penedés vineyard region (Catalonia, north east Spain), and the present research analyses 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 is mainly the presence of fragments of calcic or petrocalcic horizons, marls and sandstones. Other important properties for crops such as organic matter (OM) content and soil depth show statistically significant differences between disturbed soils and undisturbed soils (22.3–33.3% OM 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 global warming effect through depletion of soil OM.

Keywords: Soil erosion, soil degradation, soil use and management, ploughing, agriculture, 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 & 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), analysed biophysical influencing factors and predicted or modelled soil losses (Wischmeier & 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 & 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 (OM) content, the reduction in soil depth, and changes in bulk density, infiltration capacity and moisture retention (Ebeid et al., 1995; Fullen & 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 ueroded 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, for example, $^{137}$Cs derived soil erosion rates (Van Oost et al., 2005), 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 mechanization 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 have 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 & 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), has been subsidizing 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) 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 because of 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 because of 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 °C and a mean annual rainfall of 550 mm (Ramos & Porta, 1994). Rainfall mainly occurs in two periods: September to November, with frequent high-intensity rainstorms (e.g. >100 mm/h in 5-min periods), and in April to June. The rainfall erosivity factor (R) ranges from 1049 to 1200 MJ mm/ha/h/yr (Ramos, 2002). Deep ploughing <0.6–0.7 m before the planting 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 & 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 retain about 54% of the sediment 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.

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 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 (C.B.D.S.A., 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 because of 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 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, for example less OM, 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 (Martinez-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 (calcitutes, 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 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 analysed 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 contingency 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 contingency 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 were found to 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 SIS).

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 form 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 (Martınez-Casasnovas, 1998) or human-induced processes such as deep ploughing and land levelling. Nevertheless, field

| Family                                      | No. soil profiles | No. 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 Haploxeralf, fine-loamy, mixed (calcareous), thermic| 7             | 24                          |
| Typic Haploxeralf, coarse-loamy, mixed (calcareous), thermic| 2             | 3                           |
| Aquic Haploxeralf, 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                           |

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).
observations of the incision rills and gullies after very intense rainstorms confirm current erosion activity (Martínez-Casasnovas et al., 2002, 2005).

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 analysed 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.

Effects on organic matter content. The combined effects of mixing the top layers with underlying material by erosion and levelling have important effects on soil properties. Although the average 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 OM 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 & 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 & Brandsma, 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 though some viticulturists have encouraged the application of cattle manure or organic wastes every 3–4 years at rates of 30–50 Mg/ha to improve soil structure and water

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

| Type of evidence                                                                 | No. 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                          |
| CaCO₃ 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                         |

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.
infiltration (Martínez-Casasnovas & Ramos, 2006; Ramos & Martínez-Casasnovas, 2006a,b).

**Effects on calcium carbonate content.** An increasing trend was observed in the calcium carbonate content for disturbed topsoils of soils compared with 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 because of 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 because of land levelling.

**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 (Martinez-Casasnovas & Ramos, 2006). Ramos et al. (2003) through investigating 11 reference soils in the same area analysed the effects of raindrop impact on aggregate stability. Their results confirm that in general the soils are unstable to slaking and to mechanical

![Figure 5 Differences in plant development due to calcium carbonate enrichment of the topsoil in a vineyard in the Penedès region.](image_url)

| Table 3 Results of the chi-square tests on frequency data for soil structure type and evidence of mixing |
| --- |
| Soil profiles with evidence of mixing | Soil profiles with no evidence of mixing |
| **Structure type** | 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 |
| Aggregate size** | Fine | 6 | 5.8 | 2 | 2.2 |
| Medium | 26 | 25.4 | 9 | 9.6 |
| Coarse | 26 | 26.8 | 11 | 10.2 |
| Secondary structure*** | Without secondary structure | 38 | 39.9 | 17 | 15.1 |
| With secondary structure | 20 | 18.1 | 5 | 6.9 |

*P = 0.718 (Pearson’s chi-square test).

**P = 0.921 (Pearson’s chi-square test).

***P = 0.449 (Yates’ chi-square test).
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 & Martínez-Casasnovas (2006b) also report that cultivated soils after land levelling are very low in OM 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 & Martínez-Casasnovas (2006b) is 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, because of 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.

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 \(0.83 \pm 0.4\) m \((n = 59)\) compared with \(1.28 \pm 0.5\) 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 because of levelling. These results accord with those of Ramos & 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.

Conclusions

The SIS 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 OM 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 Calciixerpts and Typic Xerorthents. Fluventic Haploxerepts with a calcic endopedon; Petrocalcic Calciixerpts 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

Table 4  Levelling effects in the Penedès vineyard region

| Land levelling effect                                | Local magnitude                        | References                                    |
|-----------------------------------------------------|----------------------------------------|-----------------------------------------------|
| Land cutting and filling                            | < 5 m                                  | Jiménez-Delgado et al. (2004)                 |
|                                                    | < 2.5 m                                | Ramos & Martínez-Casasnovas (2006a)          |
| Elimination of existing conservation measures       | 26.5% increase in average annual soil  | Jiménez-Delgado et al. (2004)                 |
| measures (broad-based terraces)                     | loss                                   |                                               |
| Soil mixing                                         | 74% of the analysed 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 study                                    |
| Reduction in soil water content                     | < 20% in highly disturbed soils        | Ramos & Martinez-Casasnovas (2007)           |
| Susceptibility to soil sealing                      | Minimum hydraulic conductivity of the seal 3–6 mm/h in highly disturbed soils compared with 40 mm/h in less disturbed soils | Ramos & Martinez-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 & Martinez-Casasnovas (2006a) |
| Increase in sediment yield from levelled vineyard fields | Higher sediment concentration in disturbed soils (9 compared with 5 g/L) | Ramos & Martinez-Casasnovas (2006a) |
| Reduction in crop yield                             | Crop yield decreased depending on the degree of land levelling | Ramos & Martinez-Casasnovas (2006a) |

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the progressive loss of soil material, a reduction in OM 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.

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 OM.

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References

Blum, W.E.H. 1993. Soil protection concept of the Council of Europe and integrated soil research. In: Soil and Environment, Vol. 1 (eds H.J.P. Eijsackers & T. Hamers), pp. 37–47. Kluwer Academic Publisher, Dordrecht.

Boixadera, J., Danés, R. & Porta, J. 1989. CatSIS: Sistema de información de suelos de Cataluña. Ponencias y Comunicaciones de la XVI Reunión de la Sociedad Española de la Ciencia del Suelo. Universidad Politécnica de Cataluña y Sociedad Española de Ciencia del Suelo, Lleida, Spain. (In Spanish)

Borselli, L., Torri, D., Øygarden, L., De Alba, S., Martinez-Casasnovas, J.A., Bazzoffi, P. & Jakab, G. 2006. Soil erosion by land levelling. In: Soil Erosion in Europe (eds J. Boardman & J. Poesen), pp. 63–658. John Wiley and Sons Inc., Chichester.

C.B.D.S.A., 1983. SINEDARES. Manual para la descripción codificada de suelos en campo. Ministerio de Agricultura, Pesca y Alimentación de España, Madrid, Spain. [In Spanish]

Cots-Folch, R., Martinez-Casasnovas, J.A. & Ramos, M.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.

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.

Ebeid, M.M., Lal, R., Hall, G.F. & Miller, E. 1995. Erosion effects on soil properties and soybean yield of a Miamian soil in Western Ohio in a season with below normal rainfall. Soil Technology, 8, 97–108.

Everitt, B. 1977. The Analysis of Contingency Tables. Chapman and Hall, London.

Fenton, T.E., Kazemi, M. & Lauterbach-Barrett, M.A. 2005. Erosional impact on organic matter content and productivity of selected Iowa soils. Soil & Tillage Research, 81, 163–171.

Fullen, M.A. & Brandsma, R.T. 1995. Property changes by erosion of loamy sand soils in east Shropshire, UK. Soil Technology, 8, 1–15.

Hays, W.L. 1988. Statistics. 4th edn. Holt, Rinehart and Winston Inc., New York.

Jiménez-Delgado, M., Martínez-Casasnovas, J.A. & Ramos, M.C. 2004. Land transformation, land use changes and soil erosion in vineyard areas of NE Spain. In: Proceedings Volume of the 4th International Congress of the ESSC (eds A. Kertész, A. Kovács, M. Csuták, G. Jakab & B. Madárász), pp. 192–195. Hungarian Academy of Sciences, Geographical Research Institute, Budapest, Hungary.

Kreznor, W.R., Olson, K.R. & Johnson, D.L. 1992. Field evaluation of methods to estimate soil erosion. Soil Science, 153, 69–81.

Laflen, J.M., Elliot, W.J., Flanagan, D.C., Mayer, C.R. & Nearing, M.A. 1997. WEPP-predicting water erosion using a process-based model. Journal of Soil and Water Conservation, 52, 96–102.

Lal, R. 2001. Soil degradation by erosion. Land Degradation and Development, 12, 519–539.

Lal, R. 2003. Soil erosion and the global carbon budget. Environment International, 29, 437–450.

Lal, R. 2005. Soil erosion and carbon dynamics. Soil & Tillage Research, 81, 137–142.

Lindstrom, M.J., Schumacher, T.E., Lemme, G.D. & Gollany, H.M. 1986. Soil characteristics of a mollisol and corn (Zea mays L.) growth 20 years after topsoil removal. Soil & Tillage Research, 7, 51–62.

Lowrance, R., McIntire, S. & Lance, C. 1988. Erosion and deposition in a field estimated using cesium-137 activity. Journal of Soil and Water Conservation, 43, 195–199.

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

Martínez-Casasnovas, J.A. 1998. Soil – Landscape – Erosion. Gully Erosion in the Alt Penedès – Anoia (Catalonia, Spain). A Spatial Information Technology Approach: Spatial Databases, GIS and Remote Sensing. PhD thesis, University of Lleida, Lleida, Spain. (In Spanish and English)

Martínez-Casasnovas, J.A. 2003. A spatial information technology approach for the mapping and quantification of gully erosion. Catena, 50, 293–308.

Martínez-Casasnovas, J.A. & Ramos, M.C. 2006. The cost of soil erosion in vineyard fields in the Penedes-Anoia Region (NE Spain). Catena, 68, 194–199.

Martínez-Casasnovas, J.A., Ramos, M.C. & Ribes-Dasi, M. 2002. Soil erosion caused by extreme rainfall events: mapping and quantification in agricultural plots from very detailed digital elevation models. Geoderma, 105, 125–140.

Martínez-Casasnovas, J.A., Ramos, M.C. & Ribes-Dasi, M. 2005. On-site effects of concentrated flow erosion in vineyard fields: some economic implications. Catena, 60, 129–146.

Mengel, K., Breininger, M.T. & Bubl, W. 1984. Bicarbonate, the most important factor inducing iron chlorosis in vine grapes on calcareous soil. Plant and Soil, 81, 333–344.

Morgan, R.P.C. 2001. A simple approach to soil loss prediction: a revised Morgan–Morgan–Finney model. Catena, 44, 305–322.

Nizeyimana, E. & Olson, K.R. 1988. Chemical, mineralogical, and physical property differences between moderately and severely

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eroded Illinois soils. Soil Science Society of America Journal, 52, 1740–1748.

Nyssen, J., Poesen, J., Haile, M., Moeyersons, J. & Deckers, J. 2000. Tillage erosion on slopes with soil conservation structures in the Ethiopian highlands. Soil & Tillage Research, 57, 115–127.

Peeters, I., Rrommens, T., Verstraeten, G., Govers, G., Van Rompaey, A., Poesen, J. & Van Oost, K. 2006. Reconstructing ancient topography through erosion modelling. Geomorphology, 78, 250–264.

Phillips, J.D., Slattery, M.C. & Gares, P.A. 1999. Truncation and accretion of soil profiles on coastal plain croplands: implications for sediment redistribution. Geomorphology, 28, 119–140.

Poch, R.M. & Martínez-Casasnovas, J.A. 2002. Basic Concepts and Processes of Soil Degradation. Dekker Encyclopedia of Soil Science, Marcel Dekker, Inc, New York, pp. 260–263.

Ramos, M.C. 2002. Differences on the characteristics of the storms recorded along the year in a Mediterranean climate. Intensity and kinetic energy. In: Mediterranean Storms, 2nd Plinius Conference Pub GNDCI N 2547 (eds A. Mugnai, F. Grizzetti & G. Roth), p. 431. European Geophysical Society, Italy.

Ramos, M.C. & Martínez-Casasnovas, J.A. 2006a. Impact of land levelling on soil moisture and runoff variability in vineyards under different rainfall distributions in a Mediterranean climate and its influence on crop productivity. Journal of Hydrology, 321, 131–146.

Ramos, M.C. & Martínez-Casasnovas, J.A. 2006b. Erosion rates and nutrient losses affected by composted cattle manure application in vineyard soils of NE Spain. Catena, 68, 177–185.

Ramos, M.C. & Martínez-Casasnovas, J.A. 2007. Soil loss and soil water content affected by land levelling in Penedés vineyards, NE Spain. Catena, 71, 210–217.

Ramos, M.C. & Porta, J. 1994. Rainfall intensity and erosive potentiality in the NE Spain Mediterranean area: results on sustainability of vineyards. Il Nuovo Cimento, 17, 291–299.

Ramos, M.C., Nacci, S. & Pla, I. 2003. Effect of raindrop impact and its relationship with aggregate stability to different disaggregation forces. Catena, 53, 365–376.

Renard, K.G., Foster, G.R., Weesies, G.A., Mccool, D.K. & Yoder, D.C. 1996. Predicting Soil Erosion by Water: A Guide to Conservation Planning with the Revised Universal Soil Loss Equation (RUSLE). Agricultural Handbook No. 703, USDA, Washington, DC.

Reyes, J.M., Del Campillo, M.C. & Torrent, J. 2006. Soil properties influencing iron chlorosis in grapevines grown in the Montilla-Moriles area, southern Spain. Communications in Soil Science and Plant Analysis, 37, 1723–1729.

Rommens, T., Verstraeten, G., Poesen, J., Govers, G., Van Rompaey, A., Peeters, I. & Lang, A. 2005. Soil erosion and sediment deposition in the Belgian loess belt during the Holocene: establishing a sediment budget for a small agricultural catchment. The Holocene, 15, 1032–1043.

Schumacher, T.E., Lindstrom, M.J., Schumacher, J.A. & Lemme, G.D. 1999. Modeling spatial variation in productivity due to tillage and water erosion. Soil & Tillage Research, 51, 331–339.

Soil Survey Staff. 2006. Keys to Soil Taxonomy, 10th edn. United States Department of Agriculture, Natural Resources Conservation Service, Agriculture Handbook N 436, Washington, DC.

Soil Survey Staff. 2006. Soil Taxonomy, Basic System of Soil Classification for Making and Interpreting Soil Surveys. United States Department of Agriculture, Natural Resources Conservation Service, Washington, DC.

Van Oost, K., Van Muyse, W., Govers, G., Deckers, J. & Quine, T.A. 2005. From water to tillage erosion dominated landform evolution. Geomorphology, 72, 193–203.

Wischmeier, W.H. & Smith, D.D. 1978. Predicting Rainfall Erosion Losses. A Guide to Conservation Planning. USDA Agricultural Handbook No. 537, Washington, D.C.

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