Niki Evelpidou · Tomás de Figueiredo (editors)

Soil Protection in Sloping Mediterranean Agri-Environments
Lectures and exercises

INSTITUTO POLITÉCNICO DE BRAGANÇA

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Front: Vineyards near Régua, in the Douro Valley (UNESCO World Heritage) – soil protection structures control erosion in very steep slopes, the Port Wine grounds
Back, top: Olive grove near Mirandela (NE Portugal) – the soil is left bare by conventional tillage; nevertheless erosion rates might be low in stony areas
Back, down: Wheat field near Bragança (NE Portugal) – severe gully erosion and partial crop loss after heavy rainfalls in the initial stages of crop growth

This is the indirect outcome of an Erasmus Intensive Programme, designed and produced by the partners involved in the project labelled SPinSMEDE.

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Foreword

The long history of the Mediterranean records striking examples of success and failure of land use models and management practices, which, in the latter case, are a heavy heritage for the soil resource in this basin. At present day, many forms of soil degradation threaten Mediterranean soils as, for instance, salinization, pollution, structural degradation and erosion. There is a geographical pattern of distribution of these forms of soil degradation and soil erosion is first in rank as far as sloping areas are concerned. Corresponding to a very large surface of Mediterranean land, these are especially sensitive areas, where soils are a qualitatively scarce resource.

Sloping Mediterranean agri-environments heir a very significant part of cropping systems, crops and products traditional of the basin, vineyards and olive groves being the most relevant ones. Improvements in productivity and economic income of these areas are imperative to reduce population depletion and its impacts on territory sustainability. On the other hand, the long-term cultivated and highly eroded slopes ask for alternative land use models and management options that allow recovery of already much degraded environments. The importance of sloping areas, their land uses and misuses, comes also from their hydrological key role that, in the Mediterranean, has large consequences for water conservation, flood hazard and off-site effects of soil erosion.

Soil protection initiatives are needed to cope with the threats to soil resource highlighted above. The thematic strategy for soil protection in Europe clearly sets the topic in high priority at policy level, as the need for soil protection is there stated in specific terms. This new political background encourages defining specifically oriented rationale in view soil protection measures design and implementation. Actually, expertise acquired in the last couple of decades throughout Europe, as part of the European strong research efforts in the topic, shows the high level of specialization necessary to tackle with soil protection issues. The still growing research-borne information has to be converted into technically useful tools for “real world” problem solving. The thematic strategy for soil protection in Europe asks for such a challenge and problems posed on Mediterranean sloping areas are certainly important test-subjects.

As requirements stated in regulations eventually issued from the thematic strategy for soil protection in Europe become more specific, demand is expected to grow for technical staff able to deal with the design and implementation of soil protection measures. This is why and what for SPinSMEDE was designed, planned and organized.

SPinSMEDE, acronym for Soil Protection in Sloping Mediterranean Agri-Environments, labels an Erasmus Intensive Programne that first took place in spring 2008, in Portugal, at Escola Superior Agrária of the Instituto Politécnico de Bragança. Intensive Programmes, within the Lifelong Learning Programme, are short duration higher education programmes, fully creditated within the ECTS framework. They stem on a transnational partnership of EU Universities, where students and professors come from, as in an Erasmus mobility scheme. For SPinSMEDE two-week and 6 credits Intensive Programme, the Polytechnic Institute of Bragança, the co-ordinating institution, promoted a partnership including the Wageningen University (The Netherlands), the National and Kapodistrian University of Athens (Greece), the University of Lleida (Spain), and the Unversity of Santiago de Compostela (Spain).

The book objectives, target audience and general sequence of subjects, are all the same as those defined for the programme itself. Therefore, it is aimed at providing basic tools to assess soil degradation and to design soil protection initiatives in Mediterranean sloping areas. Rooted in both the EU thematic strategy for soil protection in Europe and the special environmental sensitivity of Mediterranean slopes, it is oriented towards the capacitation in such specific issue of post-graduation students, especially those with background in agricultural, forest or environmental engineering and those from life or earth sciences.

The programme comprises two main parts, and this is reflected in the book contents. In order to allow a better insight on the Mediterranean environment, the texts of overview lectures addressed to geography and geology, climate, soils and vegetation are also presented. Background subjects, the first part, addresses soil degradation processes and assessment, soil protection measures design and implementation applying technical and socio-economic criteria. It is intended to provide the base knowledge necessary to better understand subjects treated in the second part. Selected case studies are presented and explored in the second part, and they concern land use typical of Mediterranean slopes, such as vineyards, olive groves, forests or shrubs. Not by chance, the book falls somewhere between the classical text book and the professionally oriented handbook. As so, after a more theorectically developed topic, the reader may find exercises that set the necessary links with “real world” conditions and problems, and that guide in the application of methods to approach it.

This book assembles the texts and reading material of most of the lectures and exercises given during the two editions of SPinSMEDE, the 2008, held in Bragança, and the 2009, held in Athens (a third edition is planned for spring 2010, in Santiago de Compostela). It is felt as a still in progress work, because the relevance of this thematic seemingly requires the attention of a wider audience than the one it may reach now, and, in turn, this goal asks for editorial refinements that, for the moment, could not be achieved according to expectations. Editors and contributors deeply wish their work to serve the outstanding and demanding cause of soil resource protection in the Mediterranean sloping agri-environments.

Bragança and Athens, November 2009.

Tomás de Figueiredo, Bragança, Portugal

Niki Evelpidou, Athens, Greece

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First of all, special thanks go to the Instituto Politécnico de Bragança for the support given for this publication as well as to the Vice-President, Professor Dr. Luís Pais for his personal commitments to Erasmus Intensive Programmes and SPinSMEDE.

A sincere thanks needs to be expressed to all the professors and staff from the institutions that participated in the preparation and implementation of the programme and of this book.

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Last but not least, a word of thanks needs to be addressed to the SPinSMEDE students, whose sincere interest in the programme subjects made it a very challenging and valuable teaching experience for all lecturers.

Table of Contents

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Part I
The Mediterranean: an Overview

Geography of the Mediterranean Sea

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The Mediterranean Sea (Fig. la) covers an area of 2501.5 x 10^3 km^2, with an average depth of 1536 m and a maximum depth of 5121 m (in the Hellenic Trench), comprising a water body of 3842 x 103 km^3. The Mediterranean consists of an E-W into three main areas: (i) the western Mediterranean, which includes the Alboran Sea, the Balearic Sea and the Algerian Basin: (ii) the central Mediterranean, consisting of the Tyrrhenian Sea, the Adriatic Sea and th-trending enclosed depression, extending almost 4000 km from the Straits of Gibraltar (in the west to the coast of Lebanon (in the east). The total length of the coastline is 46 000 km; of this, some 33 750 km belong to the European margin, with the remaining 6550 km and 5700 km constituting the Asian and African margins, respectively).

This sea can be divided geographically e Ionian Sea; and (iii) the eastern Mediterranean, incorporating the Aegean Sea (and the adjacent Sea of Marmara) and the Levantine Sea (Fig. la). Water depths over the region are shown in Fig. 1b, with those <200 m, between 200 and 2000 m, and >2000 m highlighted.

The present-day configuration of the surrounding Mediterranean hinterland is the result of three related factors: (a) crustal mobility; (b) climatic variability; and (c) sea-level change. The Mediterranean is at the boundary between the Eurasian, African and Arabian plates (Fig. 2), the interaction of which resulted in the formation of the Alpine fold belt: this high relict (often >3000 m) feature extends from Gibraltar to the Middle East. The structure of live basin is extremely complex, incorporating a number of smaller secondary or microplates that have, often, very different geological histories to those of the major plates.

The Mediterranean is characterized generally by relatively narrow continental shelves bounded by steep slopes (exceptions are the northern Adriatic and the eastern Tunisian coast); the deepest parts are associated with submarine trenches, with the deepest (5121 m) being the presently-active Hellenic Trench. Fluvial sediment inputs contribute to the development of the present bathymetry, particularly within the coastal zone and on the adjacent continental shelf. Furthermore, climatic changes, sea-level rise and/or alterations in the water and sediment volumes supplied by the rivers, have impacted upon the

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N. Evelpidou & T. de Figueiredo (eds.) *Soil Protection in Sloping Mediterranean Agri-Environments: lectures and exercises*. Instituto Politécnico de Bragança, Portugal, 2009

coastal zone: in particular in the lowland coastal areas, for example the coastal alluvial plains, deltas and wetlands. It is well-documented that between 20 000 and 10 000 BP there was only limited fluvial input, followed by two periods of high sediment delivery: (i) 10000-2000 BP; and (ii) 300-0 BP. The first period occurred during the Flandrian transgression, the second occurred in historical times when increased soil erosion was associated with human activities (i.e. deforestation, agriculture, development, river regulation, etc.).

The present-day coastline of the Mediterranean is very rugged and indented in character. Some 54% of the coast is rocky with the remaining 46% consisting of various sedimentary accumulations; these are in the form of sand and rocky beaches, dunes, deltas, estuaries, wetlands and lagoons. Fluviatile sediment supplies have been extremely important, in relation to the evolution of the coastal zone and sedimentation on the adjacent sea floor. Furthermore, any modifications are likely to cause a series of socio-economic pressures on the system, as around 37% (some 133 million people) of the overall population of the Mediterranean countries live within the coastal zone.

The Mediterranean drainage basin (4 150 000 km^2) receives water-sediment fluxes from more than 169 rivers, with catchment areas >200 km^2, together with those associated with hundreds of ephemeral rivers and torrential streams. There are 19 principal rivers (with catchment areas >10 000 km^2, including the Nile River) that drain an area of 3 370 000 km^2 (the River Nile accounts for some 2 800 000 km^2), comprising about 80% of the total drainage basin. This percentage is reduced to 42% if the Nile River is excluded, increasing the potential contribution of the smaller rivers to the overall system.

The Mediterranean drainage basin could (potentially) receive annually about 650 x 10^6 t of suspended sediment, and 350 x 10^6 t of dissolved and bed-load components. These high levels of sediment supply to the coastal zone are shown by: (i) the length of the (Mediterranean) coastline (45%) consisting of sedimentary deposits; and (ii) the formation of large deltas, associated with high rates of sediment accumulation over the adjacent shelf (10-40 m, within the Holocene).

However, since the second half of the nineteenth century, this progradation has either ceased or has been reversed and coastal erosion has become dominant as a response, mainly, to the construction of dams along the course of all of the major rivers and more than half of the smaller river systems. Such constructions have inhibited the transfer of sedimentary detritus to the ocean, as more than 40% of the total area of the Mediterranean catchment area (excluding the Nile) is located upstream of the dams: this becomes 80% when the Nile River is included in the analysis, influencing accordingly the water and sediment (total) supply. This dramatic reduction in sediment supply has caused extensive coastal retreat, which ranges locally from 10 (Ebro, Po) to 100 m $year^1$ (Nile). Such coastal erosion is not restricted to the deltaic systems themselves, but extends to adjacent coastal areas; it is likely to be enhanced further, in response to climatic change and associated sea-level rise.

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The Mediterranean Climate

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Definition of the Mediterranean Climate

The Mediterranean Sea is an inland sea separating Europe from north Africa, with Asia to the east; extreme length 3860 km; area 2966,000 km^2 (Figure 1). It is linked to the Atlantic Ocean (at the Strait of Gibraltar), Red Sea and Indian Ocean (by the Suez Canal), and the Black Sea (at the Dardanelles and Sea of Marmara). The main subdivisions are the Adriatic, Aegean, Ionian, and Tyrrhenian seas; its coastline extends 46000 km, running through 22 countries.

The term Mediterranean derives from the Latin word mediterraneus, meaning "in the middle of earth" (medius, "middle" + terra, "land, earth"). This is either due to the sea being surrounded by land (especially compared to the Atlantic Ocean) or that it was at the center of the known world.

The Mediterranean Sea has been known by a number of alternative names throughout human history. For example the Romans commonly called it Mare Nostrum (Latin, "Our Sea"). Occasionally it was known as Mare Internum. Other examples of alternate names include Mesogeios (Μεσόγειος), meaning "inland, interior" (from μεσο, "middle" + γαιος, "land, earth") in Greek.

According to the Koppen definition, the Mediterranean climate is characterized by hot, dry, sunny summers and a winter rainy season (Csa, Csb); basically, this is the opposite of a monsoon climate. This climate is not only characteristic of Mediterranean lands, but is also found in California, central Chile and the extreme south of Africa (Figure 2). In summer, the climate is dominated by subtropical anticyclones, and trade winds prevail. Daily weather is greatly influenced by sea breezes and land breezes. In winter, mid-latitude depressions bring rain. Local winds, such as the Mistral of southern France and the Santa Ana of California are of great significance. In winter, temperatures rarely drop below 5°C and are more likely to be in the region of 12° to 13°C while in summer averages can be up to 27°C. Frosts are very rare in a Mediterranean climate although when they do occur they can cause great damage to crops. For this reason, vulnerable crops such as citrus fruits are usually planted on sloping

N. Evelpidou & T. de Figueiredo (eds.) *Soil Protection in Sloping Mediterranean Agri-Environments: lectures and exercises*. Instituto Politécnico de Bragança, Portugal, 2009

terrain rather than in valley floors, where in a cold spell frosts are likely to occur as cold air collects in the valley bottom.

Figure 1: *The Mediterranean Sea*

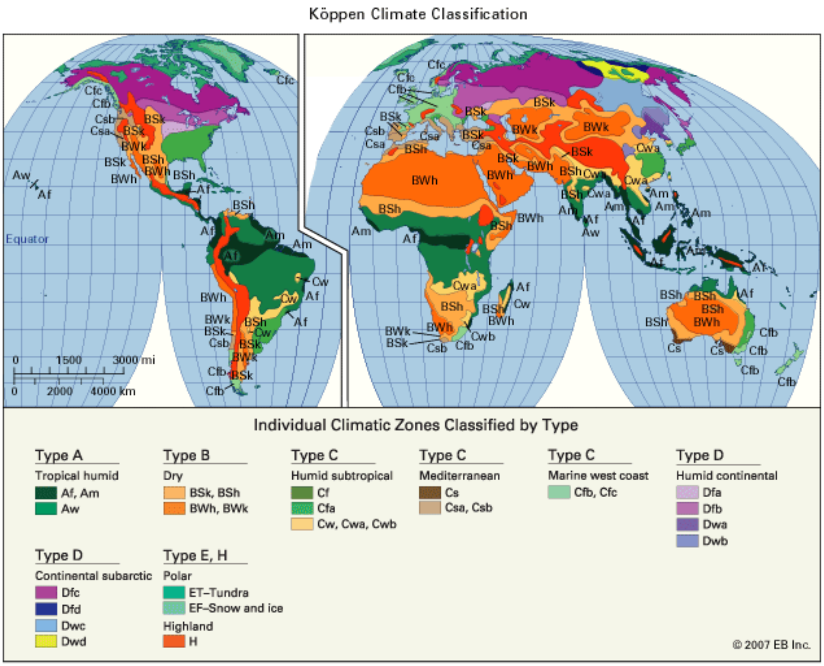


Figure 2*: Koppen climate classification*

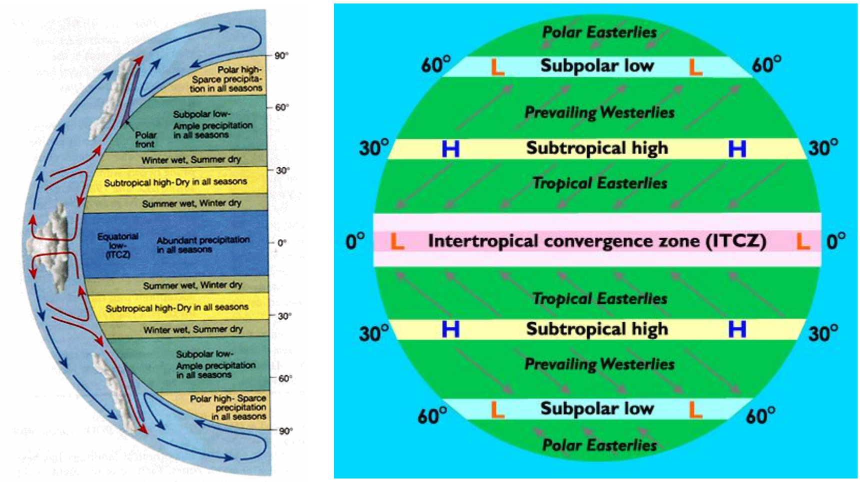


Figure 3*: Subtropical high – A belt of high pressure associated with the sinking air of the horse latitudes. (At the subtropics the air cools and descends creating areas of high pressure with clear skies and little precipitation, called the Subtropical High. The descending air is warm and dry, and produces deserts in these regions.)*

Mediterranean climate zones are associated with the five large subtropical high pressure cells of the oceans (Figure 3), the Azores High, South Atlantic High, North Pacific High, South Pacific High, and Indian Ocean High. These high pressure cells shift polarward in the summer and equatorward in the winter, playing a major role in the formation of the world's tropical deserts and the zones of Mediterranean climate polarward of the deserts. For example, the Azores High is associated with the Sahara Desert and the Mediterranean Basin's climate. The South Atlantic High is similarly associated with the Namib Desert and the Mediterranean climate of the western part of South Africa. The North Pacific High is related to the Sonoran Desert and California's climate, while the South Pacific High is related to the Atacama Desert and central Chile's climate, and the Indian Ocean High is related to the deserts of western Australia (Great Sandy Desert, Great Victoria Desert, and Gibson Desert) and the Mediterranean climate of southwest and south-central Australia.

During summer, regions of Mediterranean climate (also known as Dry-Summer Subtropical for the *Csa* areas) are dominated by subtropical high pressure cells, with dry sinking air capping a surface marine layer of varying humidity and making rainfall impossible or unlikely except for the occasional thunderstorm, while during winter the polar jet stream and associated periodic storms reach into the lower latitudes of the Mediterranean zones, bringing rain, with snow at higher elevations. As a result, areas with this climate receive almost all of their yearly rainfall during the winter season, and may go anywhere from 4 to 6 months during the summer without having any significant precipitation.

Air Temperature

The mean air temperature in the Mediterranean during the cold period (October-March) and the warm period (April-September) is depicted in Figure 4. The air temperature plots have been constructed using daily data from the NCEP/NCAR Reanalysis and refer to the normal climatological period 1968-1996.

The analysis of the mean annual air temperature time series shows that in the Mediterranean, during the 20th century, the following variations occur: In the beginning of the century, approximately at the end of the first decade, the most recent low air temperature period occurs in the Mediterranean, as in almost the whole planet. A lot of scientists claim that the end of the "Little Ice Age" period is set down during these years, a period, which affect the climate of the earth over four centuries. Further to, the air temperature rises abruptly until the beginning of 1940's and after a small drop for about a decade, the air temperature follows an increasing trend reaching a secondary maximum in the beginning of the 1960's. Following, a decreasing trend appears up to the middle of the 1970's. Finally, in the Central and West Mediterranean the air temperature rises from the end of the 1970's, while in East Mediterranean the warning is observed 15 years later. This temporal pattern is similar to the pattern appear in the Northern Hemisphere, with the exception of the recent lag warming in the East Mediterranean.

Although regional differences are relatively high, most of Europe has experienced rising temperatures of about 0.8 ^{o}C during the 20th century (IPCC 1996; IPCC 2001). Analysis of surface air temperature observed at stations located in all regions of the Mediterranean basin, indicates similar patterns to the global or and hemispheric scale; namely a cooling during the period 1955–1975 and a strong warming during the 1980s and the first half of the 1990s (Piervitali et al., 1997). However, the east–west Mediterranean difference in air and sea surface temperature trends is distinctive. In the region of Eastern Mediterranean, Repapis and Philandras, (1988) showed that, the march of the mean annual air temperature is almost parallel to the respective one in the Northern Hemisphere, from the minimum that happens in the beginning of the 20th century up to the heating of 0.6 °C observed about the middle of the century and thereafter the cooling of the decades of 1960 and 1970, after small fluctuations. The cooling observed during this period in the Northern Hemisphere is inverted soon and since the beginning of the decade of 1980 the air temperature exceeds the temperature levels corresponding to the middle of the century. Concerning the Eastern Mediterranean, the cooling is more intense of about –0.6 °C and even if it is reversed since the decade of 1980, the last two or three years seems to reach the levels of temperature in the middle of the century. Sahsamanoglou and Makrogiannis (1992) have proved that, during the period 1950-1988, the air temperature in the region of Western Mediterranean presents positive trend of 0.01-0.02 °C/year and equivalent negative trend of 0.01-0.02 °C/year, in the region of Eastern Mediterranean, as a result of the small change in circulation observed in the region of Mediterranean during the examined period. Also Metaxas et al. (1991) concluded to similar results after having examined the sea surface temperature time series for the region of

Mediterranean. Piervitali et al. (1997) found that the mean air temperature in the Mediterranean and more specifically in the Central and Western Mediterranean presents an increase of about 0.80 °C/100 years.

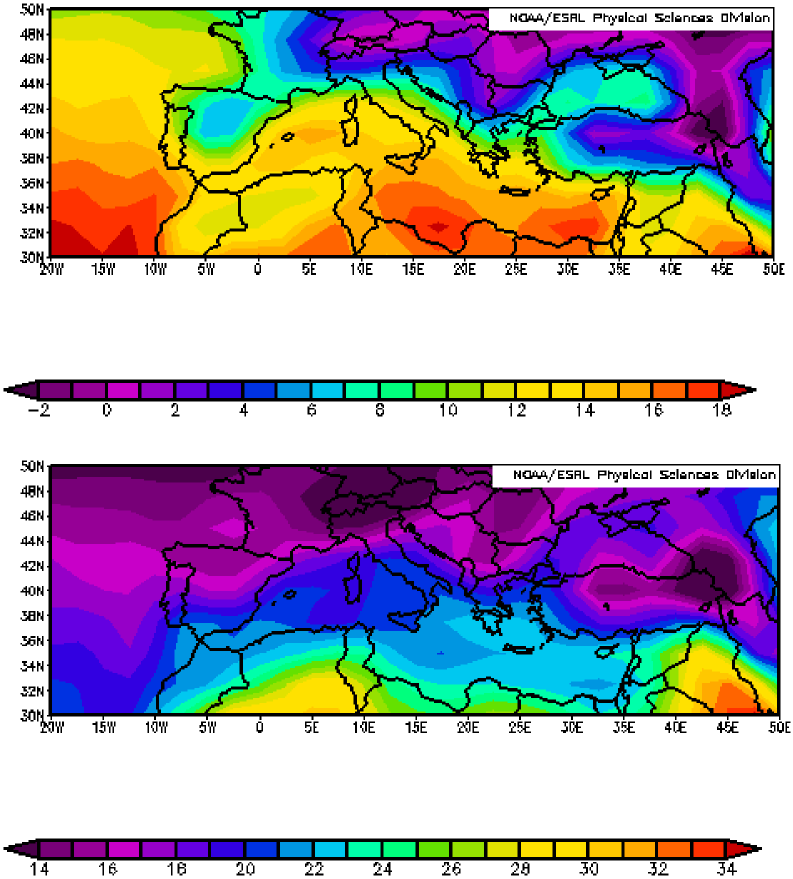


Figure 4: *Mean air temperature (°C) in the Mediterranean for the cold period (upper graph) and the warm period (lower graph).*

Regarding Eastern Mediterranean, recent studies report that the situation has begun to change at the beginning of the 1990s, because the cooling trends in mean and maximum temperatures have weakened (Turkes et al., 2002). Brunetti et al. (2000) showed positive trends for both maximum and minimum daily temperature over the period 1865–1996 in Italy, and they pointed out that the trends are greatest in the south of the country, while Moonen et al. (2002) demonstrated decreases in extreme cold events in central Italy.

Figure 5 depicts the annual mean temperature response in Europe in 21 MMD models. It is shown the temperature change from the years 1980-1999 to 2080-2099 under the A1B scenario, averaging over all available realizations for each model.

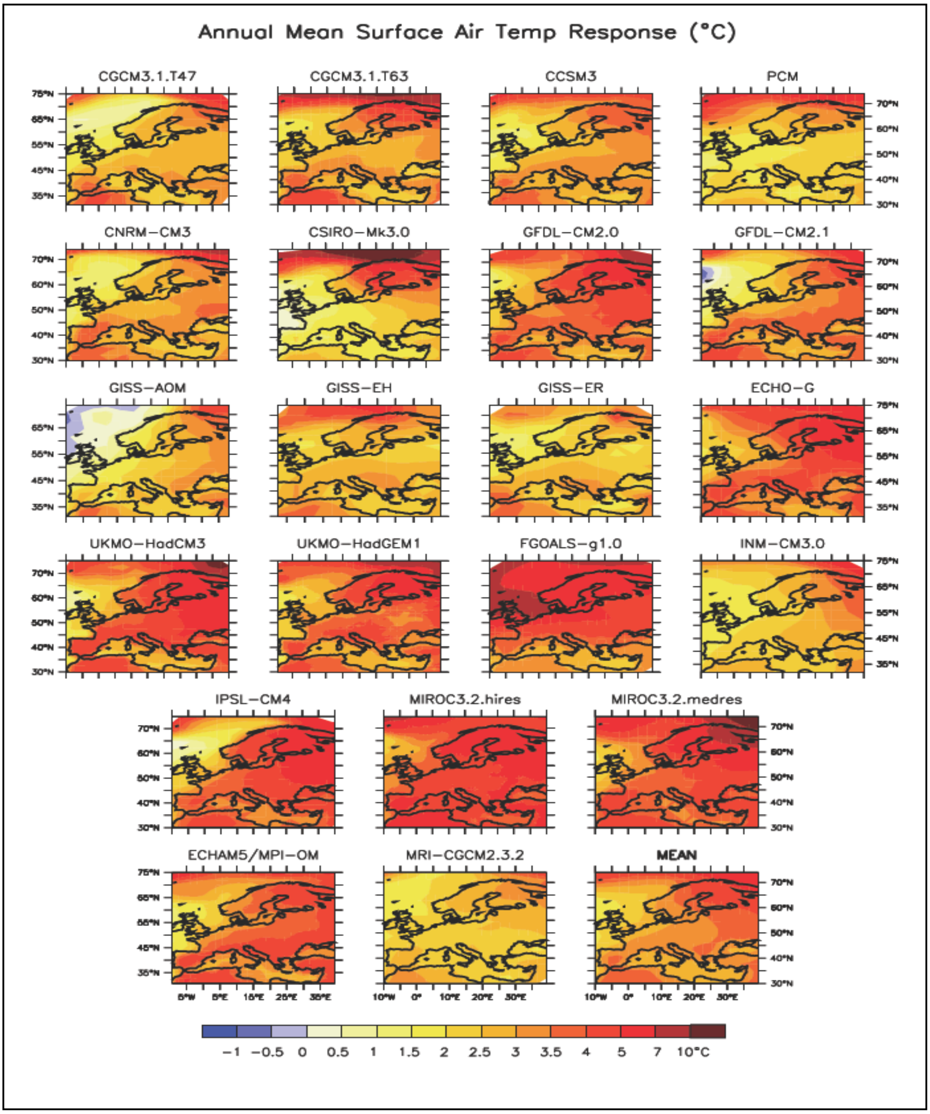


***Figure 5**: The annual mean temperature response in Europe in 21 MMD models (figure from IPCC 2007)*

A reconstruction of the Winter (DJF) averaged-mean Mediterranean temperature anomalies (with respect to 1901 to 2000) from 1500 to 2005, defined as the average over the land area 10°W to 40°E and 35°N to 47°N is shown in Figure 6 (Luterbacher et al., 2006). Cold conditions have been experienced during the Late Maunder Minimum (1675-1715) and the last decades of the nineteenth century. The analysis of anomalously wet and warm winters has revealed that in the regional-averaged time series of the Mediterranean no statistically significant changes with respect to the frequency and intensity of extreme winters have occurred since 1500. It is remarkable the increasing trend in air temperature from almost the beginning of the 20^{th} century until nowadays.

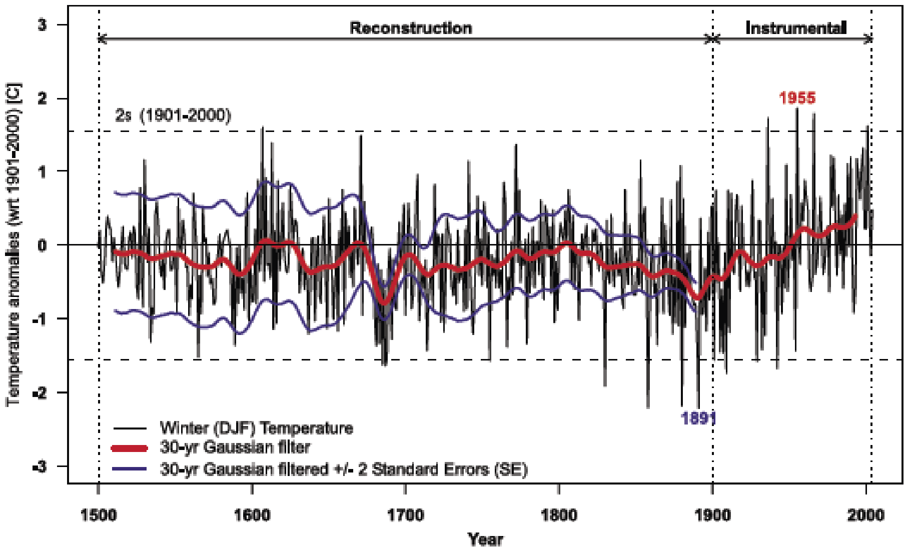
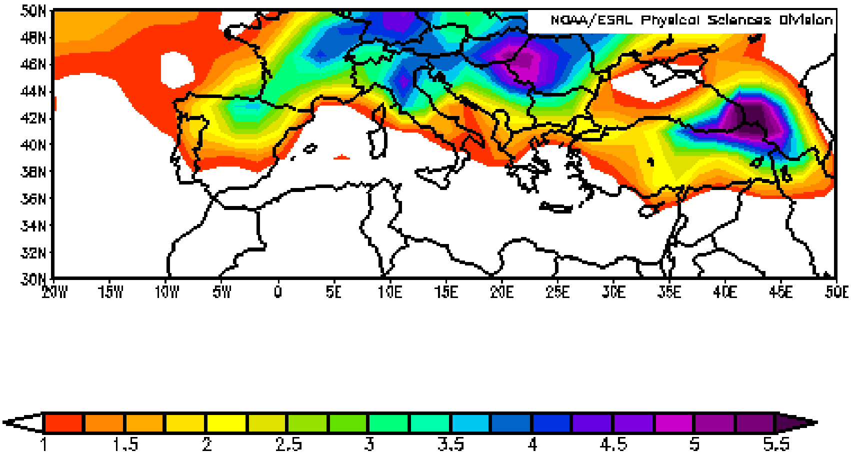


Figure 6*: Winter (DJF) averaged-mean Mediterranean temperature anomalies (with respect to 1901 to 2000) from 1500 to 2005, defined as the average over the land area 10°W to 40°E and 35°N to 47°N (thin black line). The values for the period 1500 to 1900 are reconstructions; data from 1901 to 2005 are derived from Mitchell and Jones (2005) and Hansen et al. (2001), respectively. The thick red line is a 30-year smoothings. Blue lines: ±2SEs of 30-yr Gaussian filtered reconstructions. The dashed horizontal lines are the 2 standard deviations of the period 1901-2000. The warmest and the coldest Mediterranean winter are denoted (figure from Luterbacher, J., et al., 2006).*

Precipitation

The winter rainfall exceeds three times the summer rainfall totals. This strong winter/summer rainfall contrast (Figure 7) is associated with a well pronounced seasonal cycle with summertime warm, dry conditions associated with a strong high-pressure ridge over Balkans. The axis of the ridge is displaced southward over Egypt by a trough which extends from the Persian Gulf area north-westwards towards Greece and which is associated with the Indian summer monsoon depression. The rainy season begins in October, associated with a change in the mean-wave pattern of the upper westerlies and an upper air flow which is characterized by a trough over Europe. Winter is characterized by cyclonic disturbances and low mean pressure in the Mediterranean, with higher pressure to the east associated with the Siberian high. In March and April, as the main features of the upper flow (e.g. jet streams) begin to move northward from their southernmost winter positions, the rainy season continues until May where the summer dry regime is established. A characteristic pattern of the spatial variability of the precipitation in the Eastern Mediterranean appears in Greece, where in a distance of about 350 Km the annual precipitation ranges from more than 2000 mm at the highlands of northwestern Greece to less than 400 mm at Attica and western Cyclades, while the interannual precipitation variability is high as well.

Precipitation, although mainly associated with cyclonic disturbances that originate in the Mediterranean basin (Figure 8), is also strongly influenced by local orographic effects. The winter mean surface pressure pattern shows features which result from these cyclogenetic aspects.



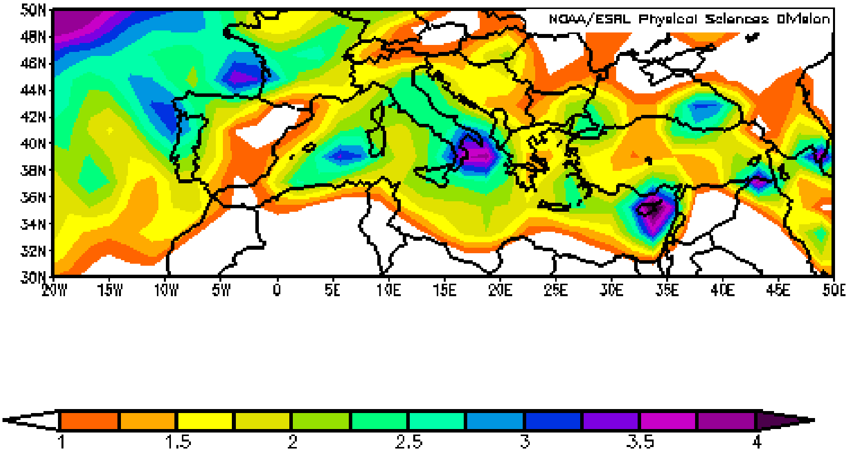


Figure 7*: Mean precipitable rate (mm/day) in the Mediterranean for the cold period (upper graph) and the warm period (lower graph).*

With regard to precipitation in the Mediterranean region, drying trends have been reported (IPCC, 2001) and occurrences of long dry spells especially during summer in the southern areas have been found (Martin-Vide and Gomez, 1999). The eastern Mediterranean especially, shows a tendency towards drier conditions (Kutiel et al., 1996; Turkes, 1998) while the western and central areas, although showing negative trends in the number of wet days and/or the total rainfall amounts, indicate an increase in intense precipitation events over the period 1951–1996 (Brunetti et al., 2001; Alpert et al., 2002). The majority of the Mediterranean region has tended toward decreasing winter precipitation during the last few decades, mostly starting in the 1970s (Figure 9) and proceeding to an accumulation of dry years in the 1980s and 1990s (Schonwiese et al., 1994; Palutikof et al., 1996; Piervitali et al., 1997; Schonwiese and Rapp, 1997). The westcentral Mediterranean area has experienced a precipitation decrease during the last 50 years (IPCC, 1996; Piervitali et al., 1997). Decreasing precipitation is also evident in large parts of the eastern Mediterranean area. Schonwiese et al. (1994) reported a pronounced significant trend towards a drier winter climate in the eastern Mediterranean area, for the period 1961–1990.

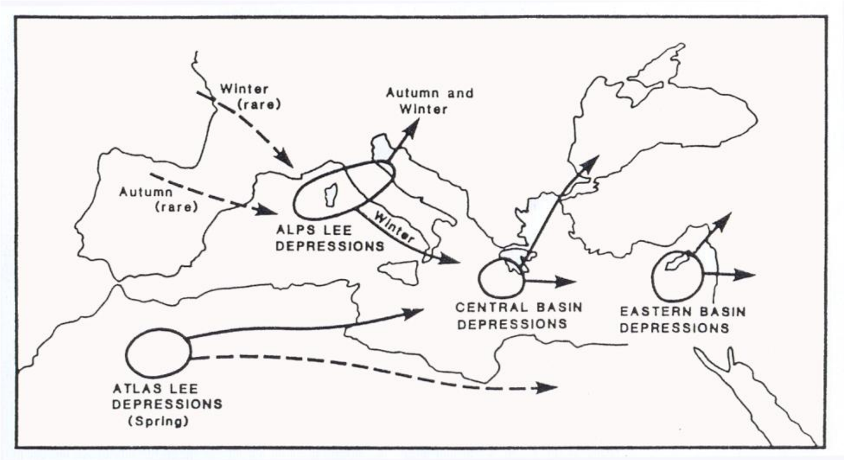


Figure 8: *Regions of cyclogenesis and principal cyclone tracks (from Wigley and Farmer, 1982).*

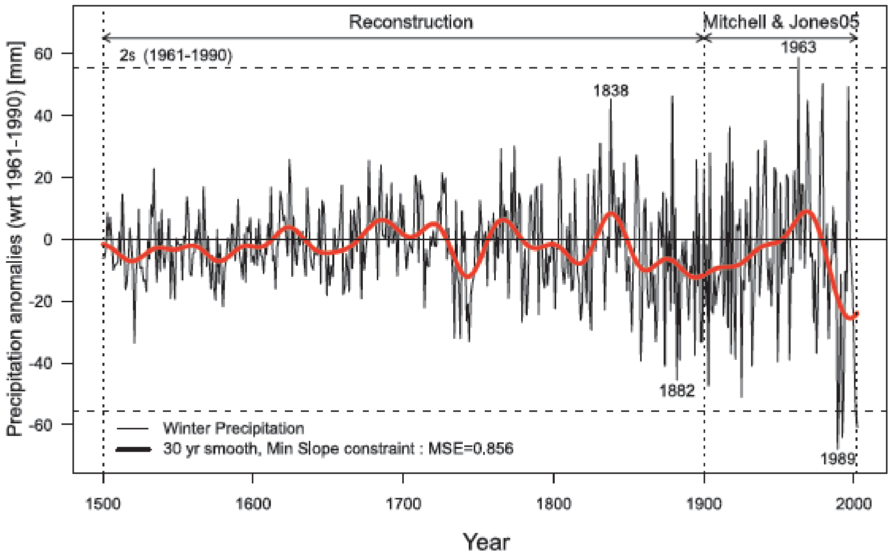


Figure 9: *Winter (Dec-Jan-Feb) averaged-mean Mediterranean precipitation anomalies (with reference to the period 1961-1990) from 1500 to 2002, defined as the average over the land area 10°W to 40°E and 35°N to 47°N (thin black line). The values for the period 1500 to 1900 are reconstructions. The thick black line is a 30-year smooth 'minimum slope' constraint. The dashed horizontal lines are the 2 standard deviations of the period 1961-1990. The driest (1989) and the wettest (1963) Mediterranean winters are denoted. (figure from Luterbacher et al., 2006, in "Mediterranean Climate Variability" published by Elsevier, Amsterdam)*

The formation of Mediterranean depressions is partly determined by transitory excursions of the polar front jet and the European trough, modified by the land-sea temperature contrast which favours cyclogenesis over warm sea waters. Depressions over the eastern basin are often associated with cold northerly airflow and lee cyclogenesis. These relationships provide a link between the local rain-producing pressure systems and larger-scale aspects of the general circulation over Europe.

From 1881 to 2003 cyclone density decreases over most parts of the Mediterranean. However, trends are not uniform and interdecadal variability is high. Figure 10 shows a counting of cyclone centres in winter for two areas, one in the western and another in the eastern Mediterranean. Significant findings are a marked decrease (about 5%) in winter (DJF) cyclone density over most of the western Mediterranean. The situation in the eastern Mediterranean, is less clear, as trends differ considerably from grid point to grid point. The different characteristics of the western and eastern Mediterranean and high interdecadal variability are presumably the source of some disagreement. In fact, other studies suggest no actually significant trend, an increase of weak cyclones in the western Mediterranean in the period 1978-1994 (Trigo et al., 2000), a positive trend in the Eastern Mediterranean, though not in the rainy season (Maheras et al., 2001).

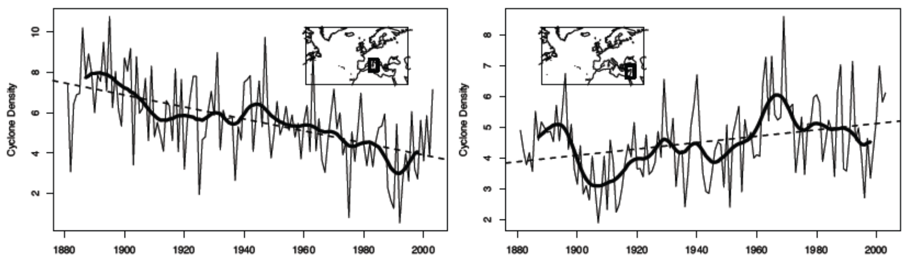


Figure 10*: Time series of average cyclone density (in units of percentage of systems/25 degree latitude squared) in winter (DJF) at boxes including nine grid points in the western Mediterranean centred at 10°W 40°N (western Mediterranean, left panel) and in the eastern Mediterranean centred at 35°W 35°N (eastern Levantine basin, right panel). The dashed lines denote the respective linear trends, in bold, a smoothed curve is plotted using a Gaussian filter with a standard deviation of 3 years (after Bhend, 2005).*

The analysis of cyclone climatology in the Mediterranean region shows trends and a moderate response to future emission scenarios. The main signal is associated to a decrease of cyclone frequency during winter in the western Mediterranean region, presumably associated with a northward shift of the storm track and persistent high phase of NAO. Such decline of cyclone frequency is suggested to continue as green house gas concentration increases, as shown by scenario simulations (Ulbrich and Christoph 1999, Lionello et al., 2002). However, cyclone activity presents large seasonal and spatial variability, with large differences from western to eastern Mediterranean and between cold and warm season (Lionello et al., 2006). Anagnostopoulou et al. (2006) studying the cyclones in the Mediterranean region, found that the Hadley Center atmospheric General Circulation Model (HadAM3P) predicts a future decrease of the frequency of the severe cyclones (<1000 hPa) at the SLP level, but the future cyclones will be more intense, especially at the 500 hPa level. Moreover, the annual mean precipitation response in Europe in 21 MMD models is depicted in Figure 11. It is shown the per cent change in precipitation from the years 1980-1999 to 2080-2099 under the A1B scenario, averaging over all available realizations for each model. Brown indicates a reduction in precipitation and green an increase (IPCC, 2007).

According to changes at the global scale, many areas experience increases in heavy precipitation events (Groisman et al., 1999; Frich et al., 2002). Such results were presented by Brunetti et al. (2001) and Alpert et al. (2002) for the central and western parts of the Mediterranean basin. Regarding the broad eastern Mediterranean region, which includes part of the central Mediterranean (Italian Peninsula) and eastern Mediterranean (Balkan Peninsula, western Turkey and Cyprus)? These two areas have contrasting precipitation trends, with the western part showing positive trends towards increased precipitation, larger precipitation total amounts and increases in intense rainfall events. In contrast, the easternmost side reveals generally negative trends indicating tendencies towards a drying climate over time. This was seen especially at the southern coastal and island stations, which present large positive and significant trends in the maximum number of consecutive dry days (CDD) index (Kostopoulou and Jones, 2005).

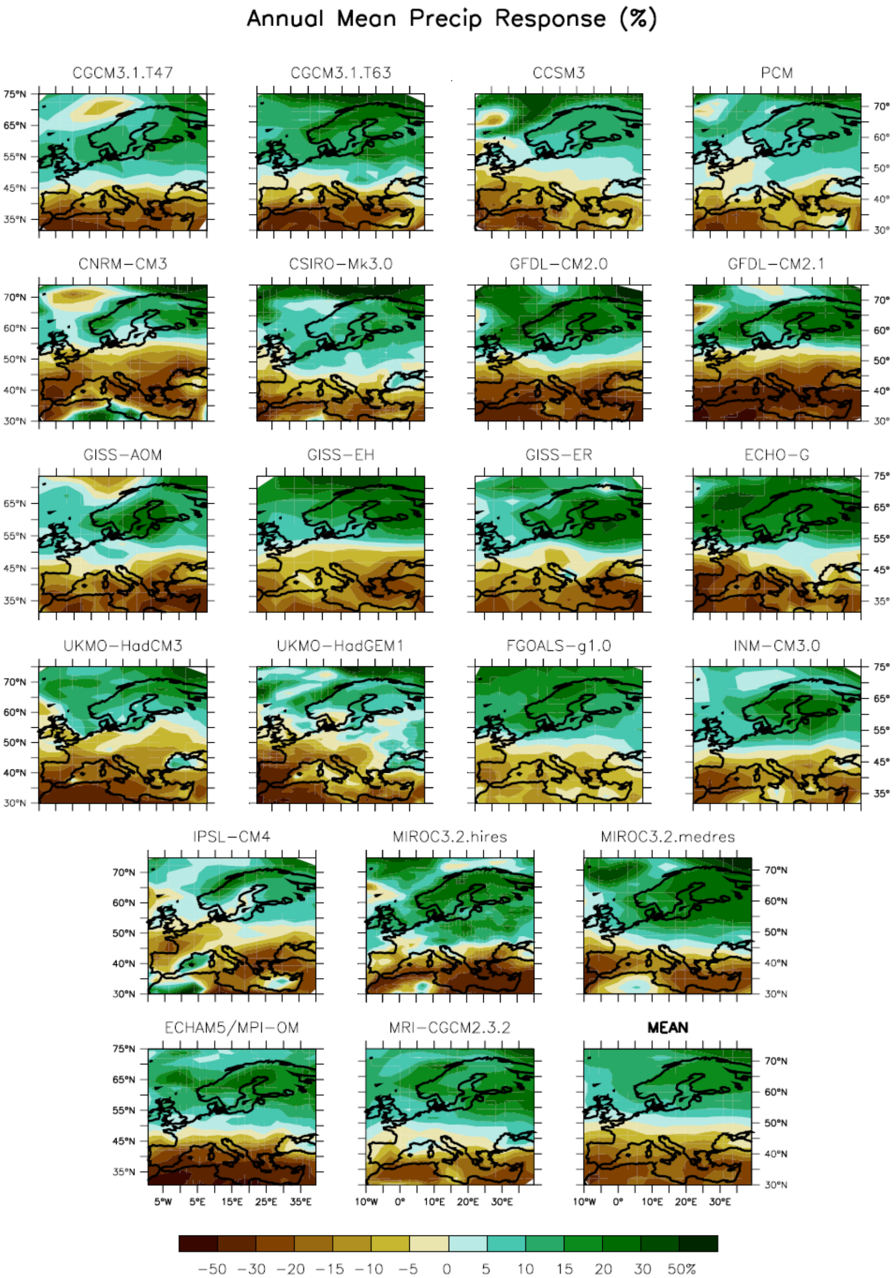


***Figure 11**: The annual mean precipitation response in Europe in 21 MMD models (figure from IPCC 2007).*

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Landcover changes in Mediterranean landscapes of Greece: implications for fire and biodiversity issues

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Keywords: Mediterannean habitats, landcover patterns, plant diversity, socio-economic changes, climate change

The structure of Mediterranean landscapes - The natural history of the Mediterranean landscapes

The landscapes of the Mediterranean Rim have a distinctive character that arises from their physiography and the long history of human development. The Mediterranean region has a basin and range topography surrounding the Mediterranean Sea, as a consequence of which it has variable geomorphological conditions. Various geological substrates are closely alternating. producing a variety of soils. The prevailing climatic conditions, although falling in the general pattern of the Mediterraneity, vary considerably, even over short distances. This physical background creates a mosaic of landscapes, which supports a broad array of habitats and a high number of species. It is broadly accepted that all Mediterranean type ecosystems evolved under the influence of environmental stresses, primarily summer drought and low soil nutrient availability. Furthermore, Mediterranean climate ecosystems of the world have been under the periodic influence of natural hazards, such as fire and tectonic instability. Consequently, the plant communities of these systems have been forced to cope with all these environmental factors and natural perturbations. In particular, Mediterranean plant communities have evolved response mechanisms to cope with fire. These mechanisms are expressed through the morphological, physiological and phenological adaptations of the plant species (Arianoutsou, 1998). However, fire, as an environmental natural hazard, does not have the same regime in all five Mediterranean climate regions of the world (Rundel, 1998). In South Africa, for example, fynbos vegetation of the Cape region usually burns at intervals of 10-15 years (van Wilgen ***et al.,*** 1992), while in California and in the Mediterranean Basin natural frequencies are usually 30-50 years or more

N. Evelpidou & T. de Figueiredo (eds.) *Soil Protection in Sloping Mediterranean Agri-Environments: lectures and exercises*. Instituto Politécnico de Bragança, Portugal, 2009

(Trabaud & Prodon, 1993; Rundel & Vankat, 1989). The Mediterranean Basin has also experienced marked climate changes during the Quaternary, which has had profound effects on plant community structure and speciation (Cowling ***et al.,*** 1996).

Plant diversity in Mediterranean landscapes

Many references indicate that the Mediterranean rim is ranked first of the five Mediterranean regions of the world in terms of the plant species diversity (Cowling ***et al.,*** 1996). It hosts approximately 25,000 vascular plants (Cowling ***et al.,*** 1996), a large number of which are range-restricted taxa. A great portion of these plants is now considered as threatened. Greece has approximately 6,000 plant taxa, a remarkable degree of endemism (~20%) and a high number of plant taxa considered as threatened (900; 600 of them endemics) (Georghiou & Delipetrou, 2000; Kokkoris & Arianoutsou, 2001).

Man and the Mediterranean Landscapes

The Mediterranean Basin was settled by humans very early. Consequently, Mediterranean-type landscapes have long ago experienced the human impact. Indigenous agriculture and animal husbandry have been practiced here for more than 10,000 years (Le Houerou, 1981; Naveh, 1998), in combination with deforestation practices and fire management. Plant community structure and diversity patterns have therefore evolved under the influence of this interaction. These patterns were kept in a dynamic equilibrium at least until the Second World War (Caravello & Giacomin, 1993). Since 1950, major changes have occurred to the economies, the livelihood and hence the landscapes of the Mediterranean countries. Initially, there were extensive rural migrations followed by agricultural intensification from the introduction of new farm machinery, new strains of cereals and tree crops and extensive application of fertilizers. The invention of new irrigation techniques made possible the use of hilly areas, so agriculture spread further. The European Community set the next milestone in this process by setting the general framework within which agricultural activities should unroll.

Current trends in landscape changes in Greece

The dynamic equilibrium between humans and the Mediterranean environment lasted until 1980 and resulted in a remarkably rich landscape. However, land abandonment, tourism development, population concentration along the coast, and the building of extended transportation networks characterized the last two decades of the 20" century (Burke & Thornes, 1998). Common Agricultural Policy (CAP) set by the European Union is also part of the puzzle. The accelerated socio-economic changes encountered during these two decades are causing major changes in the landscape patterns and the biodiversity they support (Arianoutsou, 2001). Further to this direct human influence, climatic factors, such as high temperatures and long dry periods, which alter the water status of the vegetation, may also cause dramatic changes in the landcover patterns by imposing fire events over extended landscape units (Arianoutsou, 2007).

This paper will review the current situation in the European Mediterranean ecosystems in relation to the changes they are undergone. The main drivers of these changes are related to: i) depopulation of rural areas, because of the better employment opportunities people find in the urban centers, ii) the abandonment of traditional practices in the rural areas, because of their depopulation and shift in the list of production priorities, iii) increase of the recreational and ecological value of wildland, iv) expansion of wildland –urban interface. The study- cases provided will focus on those drivers by providing evidence of the land-use changes occurred and will discuss the implications that these changes might have for the long established patterns of plant diversity and fire regime.

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The Mediterranean Soils: a quick overview

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The Mediterranean Soils: discussing the concept

Vasily Vasil'evich Dokuchaev (Russia, 1846-1903) is commonly regarded as the father of pedology, the study of soils in its natural setting. Dokutchaev, c. 1880, established the concept of zonal soils, as those showing characteristics that reflect the effect of climate in pedological processes. Examples of zonal soils were the steppe soils, the desert soils, the (coniferous) forest soils. Intrazonal and azonal were the complementary concepts.

A brief note on Dokuchaev work and legacy

Dokuchaev introduced the idea that geographical variations in soil type could be explained in relation not only to geological factors (parent material), but also to climatic and topographic factors, and the time available for pedogenesis (soil formation) to operate. Using these ideas as a basis, he created the first soil classification. His ideas were quickly taken up by a number of soil scientists, including Hans Jenny. He worked on soil science, and developed a classification scheme describing five factors for soil formation. He arrived at his theory after extensive field studies on Russian soils in 1883. His most famous work is Russian Chernozem (1883). Thanks to Dokuchaev's works a number of Russian soil terms are in the international soil science vocabulary (chernozem, podsol, gley, solonets). A crater on Mars is named in his honor. *(based on Buol et al., 2003)*

The Portuguese Soil Classification has a suborder named Mediterranean Soils – still in accordance with these concepts.

N. Evelpidou & T. de Figueiredo (eds.) *Soil Protection in Sloping Mediterranean Agri-Environments: lectures and exercises*. Instituto Politécnico de Bragança, Portugal, 2009

Table 1 – Soil Groups (and some Sub-Groups) of the Portuguese Soil Classification and corresponding groups is FAO / WRB system.

Group / Sub-Group (SRO)	Corresponding to FAO / WRB
Solos Incipientes	
Litossolos	Lithic Leptosols
Regossolos	Arenosols and Regosols
Coluviossolos	Regosols
Aluviossolos	Fluvisols
Solos Litólicos	Leptosols and Cambisols
Solos Calcários	Calcisols
Barros	Vertisols
Solos Mólicos	Mollisols
Solos Argiluviados	Luvisols and Alisols
Mediterrâneos Vermelhos e Amarelos	
Mediterrâneos Pardos	
Solos Podzolizados	Podzols
Solos Hidromórficos	Gleysols
Solos Salinos	Solonchacks and Solonetz
Solos Orgânicos	Histosols

The effect of other soil formation factors is, in many circumstances, much more determinant of soil characteristics than climate. It is the case for example of parent material or topography. These evidences contributed, through time, to the obsolescence of the concept of zonal soils, and the related concepts of intrazonal and azonal.

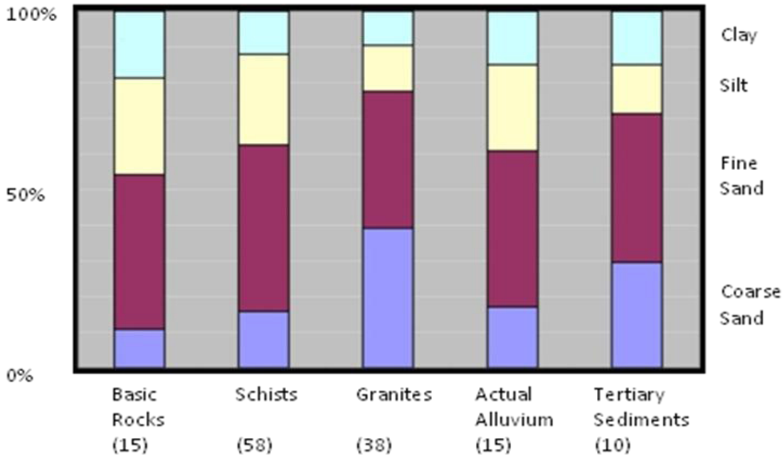

***Figure 1**: Soil particle size distribution as affected by parent material in Trás-os-Montes region, NE Portugal: average values for the number of profiles in brackets (Figueiredo, 2002).*

Currently, soil scientists tend to avoid linking soil classification concepts and soil taxonomy to climate, and, by extension, to any soil formation factor. The following quotation clearly depicts the most updated conceptual orientations adopted in actual Soil Science.

“Climate parameters are not applied in the classification of soils. It is fully realized that they should be used for interpretation purposes, in dynamic combination with soil properties, but they should not form part of soil definitions.” (IUSS/WRB, 2006:3).

It should be stressed that the International Union of Soil Sciences and the World Reference Base for Soil Resources are, respectively, the reference organization and classification system in the Soil Science domain.

A question may then arise and it regards the title of the lecture:

The Mediterranean Soils – Does this make sense?

The answer is: No (apparently!).

Actually, it makes sense because the scope of the lecture is to provide a quick overview on the soils found in this geographical area. The above quoted orientations by IUSS and WRB are then entirely accepted. The variety of soil types to be describe will show that under this geographical setting many other effects than simply climate, contribute to soil genesis and evolution. It is exactly that pedodiversity that should be understood by students in this lecture.

The thematic of Mediterranean Soils is developed along the following sections:

- Main soil groups – comprising a short description of their characteristics and geographical distribution

- Soil formation factors – mainly focused on their relative importance to actual soil properties
- Need for soil protection – briefly indicating threats and soils under threat in the Mediterranean

The Mediterranean basin

The Mediterranean basin, draining to the Mediterranean Sea, is:

- A large mid-latitude belt, roughly ranging from 30º to 45ºN
- Geographically located between the temperate regions in the North and the desert areas in the South
- With specific climatic conditions, featuring a strong seasonal contrast of precipitation, a hot dry Summers and mild wet Winters (OMBROTÉRMICOS VER GOMES GUERREiRo)

Other Mediterranean climate areas are found in California (North America), Chile (South America), South Africa and Southern Australia.

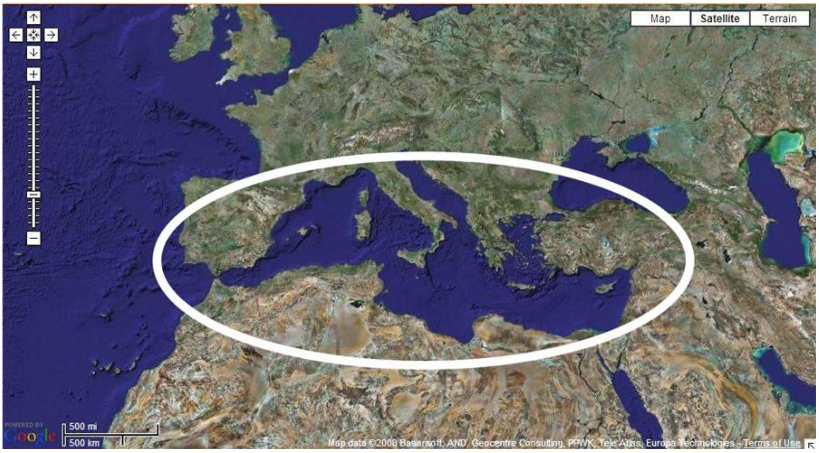

***Figure 2**: The Mediterranean Basin (image from Google Earth).*

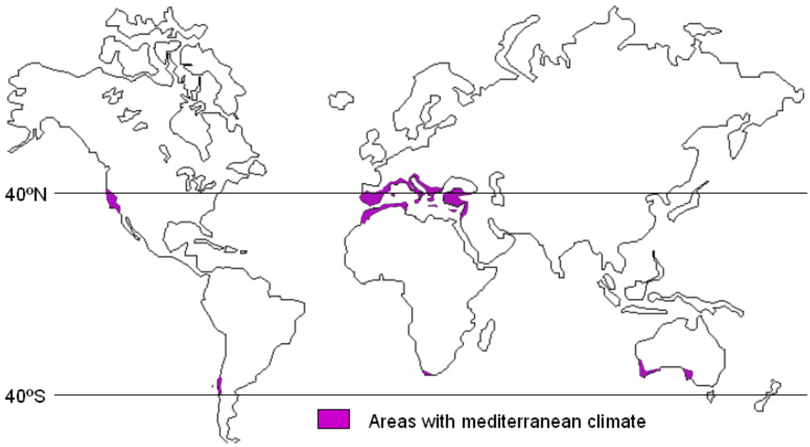

Figure 3*: Areas with Mediterranean climates (free internet access image).*

Although geographically quite restrict, the Mediterranean has an enormous civilizational importance. Actually, there is a huge contrast between the mere 2% of the globe surface where Mediterranean climate prevails, and the long array of civilizations that arose in the Mediterranean and gave the world the most remarkable heritage and intangible values, throughout history.

Main Soil groups

1. General features

Areal distribution of main soil groups is depicted below, following the FAO system of soil classification. It can be seen that:

- Three groups cover more than 50% of the area and they are the Calcicols (20%), the Cambisols (16%) and the Luvisols (16%)
- To these Vertisols (4%) should be added, due to their areal relevance when compared with those included in Others
- Label Others comprises a large list of soil groups, including Leptsols, Regososls, Alisols, Fluvisols, Gleysls, Gypsisoils, Solonchacks, Solonetz
- Low development soils dominate, as Calcisols and Cambisols, together with those qualified as incipient due to practically no evidence of pedogenetic activity, as Regosols and Leptosols
- Calcisols reflect Carbonates importance as lithological materials in the Mediterranean
- More developed soils, as for example the Luvisols, are important in areal terms but they are far from dominant

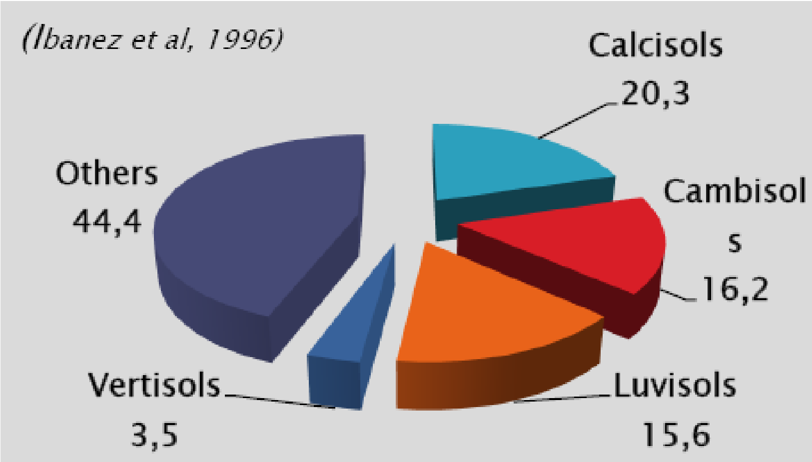

Figure 4: Areal distribution of main soil groups in the Mediterranean (Ibanez et al. 1996).

"At world level, despite the small area of the Mediterranean landscapes, their pedodiversity is outstanding" (the second after Mountain climates) (Ibanez et al. 1996).

A very schematic description of each one of the main soil groups follows, simply indicating the most relevant features of these soils.

2. Brief description

a. Calcisols

- Soils with secondary CaCO3 accumulation (Bk or Ck horizons)
  - Calcic, hypercalcic or petrocalcic horizon at less than 100cm depth
  - Calcic horizon has more than 15% CaCO3 equivalent
  - Hypercalcic horizon has more than 50% CaCO3 equivalent
  - Petrocalcic is a hardned hypercalcic horizon (Bkm, Ckm)
- Mostly clayey, high pH
- Occurrence in dry environments (dominant in South Mediterranean)
- Mostly cultivated

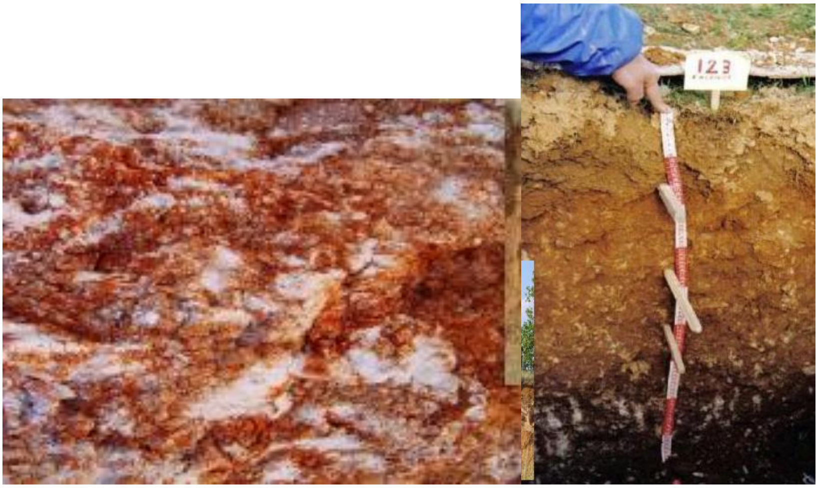

Figure 5: *Calcisols profile (internet free access images).*

b. Cambisols

- Soils that show soil formation features by either:
    - Colour change compared to parent material
    - Soil structure development
    - Leaching of carbonates
    - Formation of silicate clays and sesquioxides as a result of weathering of primary minerals
    - But lack sufficient soil development to classify otherwise
- Varied physical-chemical characteristics
- One of the most widespread soils
- Mostly cultivated

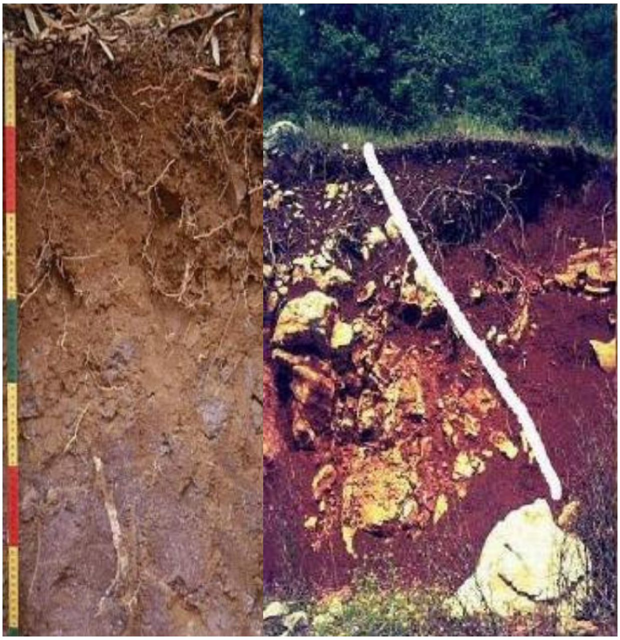

***Figure 6**: Cambisols profile (internet free access images).*

c. Luvisols

- Soils well-developed, with argic subsurface horizon (Bt), due to illuvial clay accumulation
- Mostly chromic (reddish) in drier areas
- Fertile soils, mostly cultivated (also forested)

d. Vertisols

- Soils moderately developed, clayey in the entire profile, shrink-swell clays (montmorillonite)
- Poorly structured (prismatic aggregates), badly drained, chemically fertile
- Grazing or cultivated areas

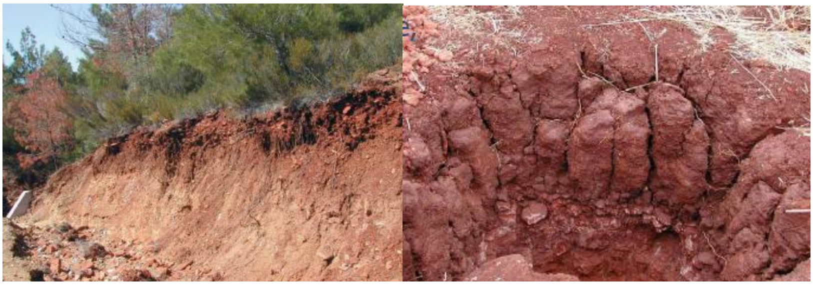
***Figure 7**: Luvisols and Verti sols profile (internet free access images).*

Other soil groups

- Leptsols (shallow, stony, over hard-rock) – mountainous steep areas
- Regosols (coarse material, lacking B horizon) – sometimes colluvial deposits
- Alisols ("leached Luvisols") – wetter or more acid environments than Luvisols
- Fluvisols (deep, fine textured, fertile) – alluvial plains
- Gleysls (hydromorphic, gray colours) – poorly drained areas (depressions or alluvial plains)
- Gypsisoils (secondary gypsum accumulation) – drier areas than Calcisols
- Solonchacks / Solonetz (excess Na) – brackish water or drier areas than Gypsisols

Figure 8*: Salt marsh where saline soils develop (internet free access images).*

Soil formation factors

After describing the main soil groups identified, following a rank in areal importance, addressing to soil formation factors helps explaining their geographic distribution.

Since Jenny, in 1940, the soil, as characterized by its properties, is taken as a function or the outcome of combined effects of the soil formation factors. Soil formation factors are climate, parent material, topography, organisms and time. In practical terms, organisms are restricted to the most visible group acting to form soil – vegetation. In cultivated areas, man acts also as a soil formation factor. The effects of man in soil are a result of continued and long lasting land use systems. As so, land use may be taken as a soil formation factor in areas where the soils are cultivated since long, as it is the case of very many in the Mediterranean.

In this section soil formation factors contributing to characteristics and distribution of soils in the Mediterranean are treated as follows:

- Climate – climatic features relevant for soil formation
- Relief – geological and physiographic features
- Parent material – main lithologies
- Vegetation, land use, man and time – a long history of land use and misuse

Figures below illustrate the effect of soil formation factors on selected soil properties, taking as an example the soils of NE Portugal.

1. **Climate**

Climatic features relevant for soil formation in the Mediterranean are:

- Sesonal contrast of precipitation

  Driving seasonal (not continuous) leaching, favouring eluviation-illuviation mechanisms, with development of argic horizon (Bt, typical of Luvisols and Alisols).
- Summer drought

  Conditioning rock weathering and pedgenesis, limited to winter when chemical and biological activies are lowest.
- Precipitation amount

  Mostly low (below 600mm annual average), limits depth range of salts leaching and secondary precipitation, favouring calcic (Ck) and gypsic (Cy) horizons (or even their hardened version: petrocalcic and petrogypsic).
- Precipitation concentration

  Promotes erosion (a selective particle entrainment process) and, together with the previously mentioned low precipitation amounts, limits rock weathering rates, favouring tony soils.

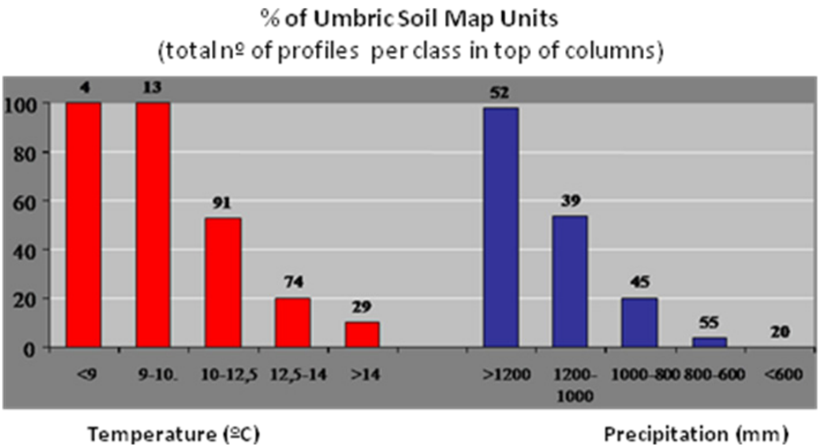

***Figure 9**: Effect of Temperature and Precipitation (annual averages) on soil organic content as assessed by the presence of a Umbric (A organic rich) horizon in NE Portugal soils (Figueiredo 2002).*

2. **Relief**

Relief addresses to physiographic features and these are strongly dependent on the geological history. The following aspects are relevant to soil genesis:

- Recent orogenic movements – Mediterranean higher mountain ranges rised under Alpine orogeny and tectonic activity persists due to the position and movement of plate margins (African and Eurasiatic)
- Polygenetic landscapes – recent and ancient land forms co-exist
- Main morphological features – denuded hillslopes, extensive floodplains, torrential dissection by ephemeral streams, combine to display
- Diverse but dominantly vigorous relief – sloping land is the major part of Mediterranean, favouring erosion instead of weathering and pedogenesis, outcoming shallow and stony soils in steeper areas

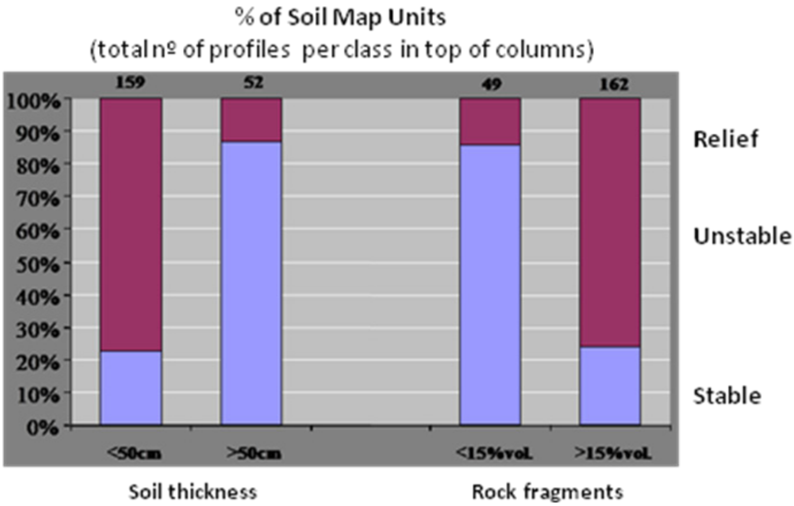

Figure 10: *Effects of geomorphological stability (associated to relief) on soil thickness and stoninesss in NE Portugal soils (Figueiredo 2002).*

3. Parentmaterial

Main lithologies found in the Mediterranean basin support the following synthetic elements:

- Diverse lithologies, although sedimentary material prevails
- Limestones – widespread, in all topographic positions
- Detritic origin common – sandstone, clay, mainly flatter areas
- Metamorphic and magmatic – respectively, schists and granite or volcanic, steeper and higher areas
- Gypsic and saline parent material – drier and lowlands

Parent material affects soil depth, texture, clay mineralogy, cation exchange capacity and base saturation, pH, and may also influence the physical properties of soil. In fact, loose sediments allow development of deep soils, as it is the case of Fluvisols, while soil derived from harder parent materials may vary widely in depth, according to weathering rates and topographic position. Over acid magmatic or metamorphic rocks, as granites and schists, respectively, soils are generally acid with low in base saturation. On the contrary, either over basic magmatic rocks or over sedimentary materials as carbonates and sulfates, pH and base saturation are both high.

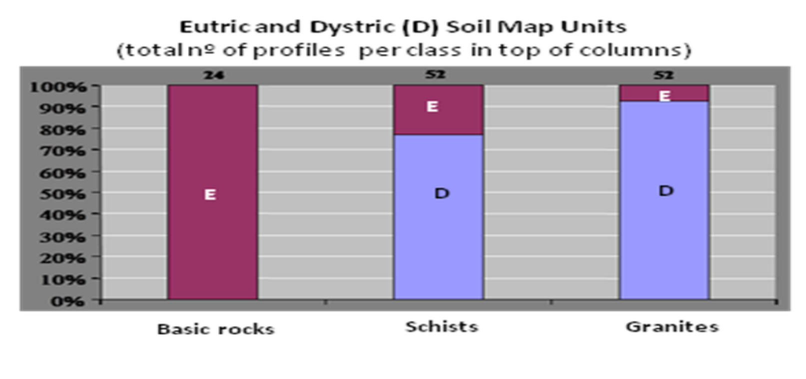

***Figure 11**: Occurrence of Eutric (non or slightly acid) and Dystric (acid or very acid) secondary units as affected by the lithology of parent material in Trás-os-Montes NE Portugal soils (Figueiredo 2002).*

4. Vegetation, landuse, time and man

The Mediterranean has a long history of good land use examples but has also striking misuse examples, with highly degraded soils as a result. Together with these strongly humanized landscapes, areas of natural or semi-natural vegetation concur to increase pedodiversity in the Mediterranean basin. The role of vegetation and land use systems in the Mediterranean as regarding soil genesis and development, may be stated as follows:

- Vegetation and water – very strong dependence of soil cover density and biomass on summer watershortage and climate aridity.
- Long term land use – ancient as actual civilizations need land to cultivate for food production.
- Low carbon contents – lowbiomass, high mineralization and low humification rates (driven by climate and man), low nutrient pool, weak structure, high erodibility.
- Erosion cycle – less vegetation cover, more erosion, less soil depth, less soil nutrient and water storage, less vegetation (and control mechanisms).

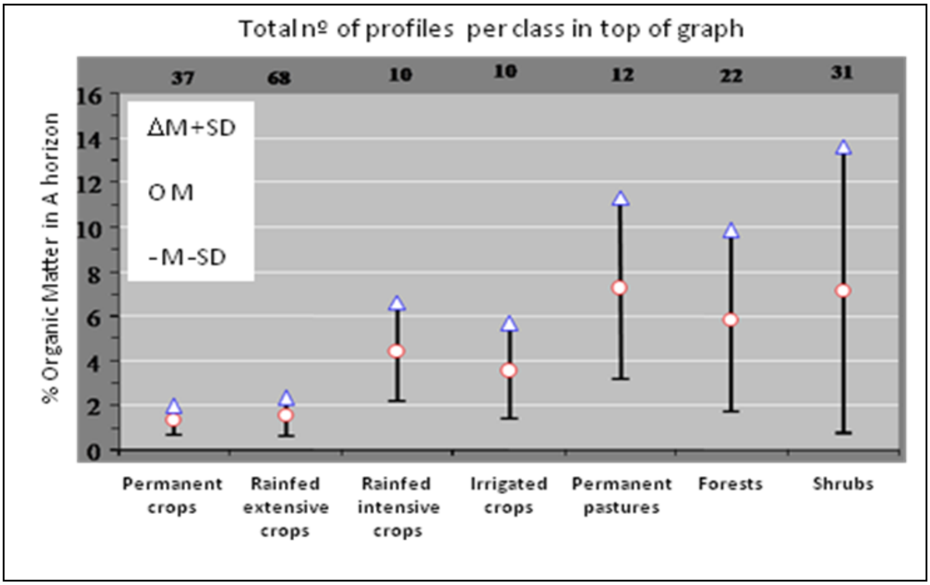

Figure 12*: Organic content of soils as affected by vegetation and land use in NE Portugal: average (M) and range (SD, standard deviation) in A horizon (Figueiredo 2002).*

The Mediterranean: need for soil protection

The European Thematic Strategy for Soil Protection states:

- main threats for European soils are erosion, organic matter decline, compaction, salinisation, landslides (all occuringin specific risk areas), contamination and sealing (and flooding).
- erosion (12%) and organic matter decline (45%) are, by far, those that affect larger areas (percent of Europe's surface).
- Mediterranean sloping agri-environments are central for Europe's soil protection strategy, as they are:(i) threatened by erosion and a low organic status(ii) very sensitive to land use changes(iii) hosting production systems that support people, quality.

On this section, and as a synoptic closing statement of the lecture, it is worthy to call back part of the text of the Foreword of this book, also the Welcome word of this Erasmus Intensive Programme (see SPinSMEDE website for the full text):

In the Mediterranean, its long history records striking examples of successes and failures of land use models and management, which, in the latter case, are a heavy heritage for the soil resource in this basin. At present day, many forms of soil degradation threaten Mediterranean soils as, for instance salinization, pollution, structural degradation and erosion. There is a geographical pattern of distribution of these forms of soil degradation and soil erosion is first in rank as far as sloping areas are concerned. Corresponding to a very large surface of Mediterranean land, these are especially sensitive areas, where soils are a qualitatively scarce resource. They heir a very significant part of cropping systems, crops and products traditional of the Mediterranean, vineyards and olive groves being the most relevant ones. Improvements in productivity and economic income of these areas are imperative to reduce population depletion and its impacts on territory sustainability. On the other hand, the long-term cultivated and highly eroded slopes ask for alternative land use models and management options that allow recovery of already much degraded environments. The importance of sloping areas, their land uses and misuses, comes also from their hydrological key role, that, in the Mediterranean, has large consequences for water conservation, flood hazard and off-site effects of soil erosion. To cope with threats to soil resource highlighted, soil protection initiatives are needed.

The thematic strategy for soil protection in Europe clearly sets, at policy level, the topic in high priority, as the need for soil protection is there stated in specific terms. This new political background encourages defining specifically oriented rationale in view soil protection measures design and implementation. Actually, expertise acquired in the last couple of decades throughout Europe, as part of the European strong research efforts in the topic, shows the high level of specialization necessary to tackle with soil protection issues. The still growing research-borne information has to be converted into technically useful tools for real world problem solving. The thematic strategy for soil protection in Europe asks for such a challenge and problems posed on Mediterranean sloping areas are certainly important test-subjects.

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Part II
Soil degradation and soilprotection: background subjects

Soil erosion

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Soil erosion

Soil erosion is as old as the earth itself. Roo (1993) defines soil erosion as the removal of soil by forces of nature more rapidly than various soil-forming processes can replace it. It is caused by the interaction between rainfall as an erosive agent and soil as a medium that is detached and transported (Nakos, 1983). These processes are generally determined by locational factors including climate, soil, relief, vegetation and man made soil conservation measures.

Soil erosion by water is a serious problem in many parts of the world. It is categorized as the most serious environmental problem because it threatens agriculture and the natural environment (Hagos, 1998). Erosion degrades soil by removing topsoil, decreasing plant nutrients, rooting depth and water reserve. Augmentation of population, overgrazing, agricultural activities on steep slopes with marginal soils in combination with heavy and sporadic rainfall, make huge areas extremely sensitive to erosion (Petter, 1992). The degradation of soil by erosion is of particular concern because soil formation is extremely slow (Hagos, 1998).

Among the consequences of soil erosion is the reduced ability of cultivating possibilities on eroded hill slides and sedimentation of water reservoirs, which reduces irrigation possibilities and leads to decreased agricultural production. The potential erosion risks are higher under intensive arable land use than under forestry or pasture land uses.

Soil water erosion is very dynamic and spatial phenomenon which depends on relief geometry and surface properties influencing overland flow (Jaroslav et al., 1996). Generally, there are six major erosion factors i.e. rainfall, slope gradient and steepness, soil, surface cover and management as explained in the following sections.

Rainfall

Soil loss is closely related to rainfall through the combined effect of detachment by raindrops

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striking the soil surface and by runoff (Yassoglou, 1989). The ability of rainfall to cause erosion (erosivity) depends on characteristics such as rainfall energy and rainfall intensity particularly half-hour rainfall. These characteristics determine the ability of raindrops to detach soil particles and the possible occurrence of surface runoff, a primary means for transportation and deposition of detached soil particles (Nakos, 1983). The amount of rainfall governs the overall water balance and the relative proportion that becomes runoff (Hagos, 1998). Erosion is related to two types of rainfall events, the short-lived intense storm where the infiltration capacity of the soil is exceeded, and the prolonged storm of low intensity, which saturates the soil before runoff begins. In addition to the rainfall amount, drop size distribution, kinetic energy and depth of overland flow are important characteristics affecting splash detachment. Detachment is due to the size of the raindrop and its velocity. Big raindrops have high erosive power to detach the soil particles.

Soils

The effect of soil on erosion is reflected through the resistance of soil to both detachment and

transport, defined through the soil erodibility factor (Morgan, 1995). Soils with high erodibility index are more sensitive to erosion than soils with low erodibility index. Soil erodibility (K-factor), varies with soil characteristics, e.g., texture, bulk density, shear strength, organic matter content, aggregate stability, infiltration capacity, chemical properties and transportability of loosened soil particles (Yassoglou, 1989). The aggregate stability of a soil determines how easily soil particles can be detached. Transportability determines how easily these loosened soil particles can be washed away. Particle size is an important element in soil erodibility. Larger particles are more resistant to transport due to greater force entailed to move them. However, in soils with particles less than 0.06 mm, the erodibility is limited by the cohesiveness of the particles. This is a reversed relationship compared to that of particle size. The particles that are less resistant to erosion are therefore silt and fine sand (Petter, 1992). Soil texture also influences the infiltration capacity. This is defined as the maximum sustained rate at which soil can absorb water, and depends on pore size, pore stability and the form of the soil profile. Clay soils have a low infiltration capacity and create more overland flow than soils consisting of coarser material, with higher infiltration capacity (Petter, 1992).

Vegetation

Vegetation covers is a very crucial factor in reducing soil loss (Petter, 1992). In general, as the protective canopy of land cover increases, the erosion hazard decreases (Yassoglou, 1989).

It protects the soil against the action of falling raindrops, increases the degree of infiltration of water into the soil, maintains the roughness of the soil surface, reduces the speed of the surface runoff, binds the soil mechanically, diminishes micro-climatic fluctuations in the uppermost layers of the soil, and improves the physical, chemical and biological properties of the soil (Petter, 1992). As long as vegetation cover is unbroken, erosion and runoff are small despite erosivity of the rainfall, slope steepness and soil instability. The effects of vegetation cover on erosional processes especially on surface erosion are varied depending on the type of vegetation cover, density, undergrowth cover and litter. These establish the interception loss, absorption of kinetic energy and increasing water infiltration. Land with good cover allows soil retardance to overland flow. Vegetation acts as a protective layer or barrier between the atmosphere and the soil. The above ground cover absorbs energy of falling raindrops, running water and wind, so that less is directed at the soil. The below ground mechanism comprising the root system contribute to the mechanical strength of the soil (Hagos, 1998).

Management

In circumstances where farmers farm in marginal and very steep slopes, soil erosion can be accelerated if there is no proper conservation techniques applied. Proper management practices such as terracing on steep slopes, mulching, and crop alternation can significantly reduce soil erosion. On the other hand improper use of land, such as reclamation of forest area, cultivation of steep slopes without conservation can drastically promote soil erosion.

Topography

Slope steepness and slope length are considered to have a strong relationship to erosional process (Nakos, 1983). Therefore both of them are useful in quantitative evaluation of erosion. Slope gradient and slope length are the common parameters used in erosion modeling (Petter, 1992). Slope gradient has an exponential relationship with erosion. Steep slopes are more prone to soil erosion because the erosive forces splash, scour and transport all have a greater effect on steep slopes (Hudson, 1995). On the other hand, longer slopes are more susceptible to soil loss due to larger build up of surface runoff, velocity and depth.

Scale of erosion assessment

Soil erosion has been assessed at different levels using a variety of methods (Mainam, 1999). These can be grouped into three levels following the objectives of assessment. They contain: micro-plot level, plot level and watershed level. At micro-plot level (0.5 to 2 m2), evaluations are conducted under controlled conditions to study erosion processes such as splash or interill erosion and the effects of soil properties on them. Studies at plot level are conducted mainly under natural conditions. The scale varies from a few square meters to a few hectares.

Soil erosion scale at field scale allows the evaluation of the effects of farming practices, land use systems or topographic factors. The study of soil erosion at watershed level involves areas covering hundreds and thousands of square kilometers and deals with streams and river basins. It is used to assess the denudation rates of major river basins, mountain system, continents, and ecological regions (Mainam, 1999).

Soil erosion modeling

Renschler (1996) defines a model as a simplification of processes and their interactions with the aim of extracting, evaluating and simulating the relevant processes. The objective of soil erosion models is either predictability or explanatory (Petter, 1992). Erosion models are currently the most feasible approach in generating data on erosion hazard (Meijerink and Lieshout, 1996). Models elucidate on erosion through mathematical equations in a simplified form. However the reality to be represented can differ from model predictions (Nakos, 1983). This can be due to the way of representation of particular models as well as the spatial and temporal scales model.

Several models have been developed and many new ones are in the process of being developed. The main categories of erosion models are empirical, physical, stochastic, hybrid and rule based. Most erosion models are of empirical type. Stochastic models are models in which any of the variables included in the model are regarded as random variables having distributions in probability. If all variables are regarded as free from random variation, the model is regarded as deterministic (Roo, 1993).

Models can be lumped or distributed. Lumped models take no account of the spatial distribution in the input variables (S), or of the spatial variation in parameters characterizing the physical processes acting upon input. Procedures may be used to calculate effective values for the entire area. Distributed models incorporate data concerning the spatial distribution of variables together with computational algorithms to evaluate the influence of the distribution on simulated behavior (Roo, 1993). Furthermore, models can be conceptual or empirical.

A model is conceptual if the physical processes acting upon the input variable to produce the output variable are considered in terms of the physical laws. Empirical models are by strict definition based on observation and experiment, not on theory. The term physically based models is used to replace conceptual distributed models, because if models are physically based, meaning firmly based in our understanding of the physics of the processes, they are necessarily distributed because the equations on which they are defined generally involve one or more space coordinates.

1. Empirical models

Empirical models describe erosion using statistically significant relationships between assumed important variables where a reasonable database exists (Kadupitiya, 2002). Empirical models are based on defining important factors through field observation, measurement, experimentation and statistical techniques relating erosion factors to soil loss (Petter, 1992). In empirical models, the inherent processes involved are not used and the models can only be operated in the designed direction where inputs go into one side of the equation and the output on the other side. Empirical models are quick in predicting erosion, but are site specific and require long-term data (Elirehema, 2001). Most models used in soil erosion studies are empirical models. The most widely used empirical model is the USLE. Others include SLEMSA, DUSLE, RUSLE, MUSLE etc, which are based on modifications made on USLE.

Details of the most used empirical models are briefly discussed below:

The USLE (Wishmeier and Smith, 1978) is the most widely used model in predicting soil erosion. It is used in education and research as a starting point in developing understanding of erosion hazard prediction because of its simplicity and clarity (Hagos, 1998). Many scientists have proposed changes, but all are woven around the same concept of rainfall erosivity, soil erodibility, slope length, slope class, land cover and land management factors are taken as directly proportional to the rate of annual soil erosion (Sohan and Lal, 2001). Since the model was developed based on simulation in the East of the Rocky Mountains, its validity in areas outside the USA is regularly questioned (Roo, 1993). The USLE model estimates average annual soil loss by sheet and rill on those portions of landscape profiles where erosion but not deposition is occurring. The model does neither predict single storm event nor does it predict gully erosion (Foster, 1982; Keneth et al., 1991). The model is also one-dimensional and static with limited possibilities for analysis of phenomenon dynamics (Jaroslav et al., 1996). The modified universal soil loss equation is one of the modified versions of the USLE. In MUSLE, the rainfall energy factor was replaced with runoff. The runoff factor includes both total storm runoff volume and peak runoff rate. Compared with USLE, this model is applicable to individual storms, and eliminates the need for sediment delivery ratios, because the runoff factor represents energy used in detaching and transporting sediment. The main limitation is that it does not provide information on time distribution of sediment yield during a runoff event. It is strictly a sediment yield equation and should not be used where detachment controls sediment yield (Roo, 1993).

RUSLE is a revised version of USLE, intended to provide more accurate estimates of erosion (Renard et al., 1994). It contains the same factors as USLE, but all equations used to obtain factor values have been revised. It updates the content and incorporates new material that has been available informally or from scattered research reports and professional journals. The major revisions occur in the C, P, and LS factors. The C or cover management factor is now the product of four sub factors: prior land use, canopy cover, soil surface cover and surface roughness.

The MMF model is an empirical model for predicting annual soil loss from field-sized area on hill slopes (Morgan, 2001). It was aimed at bridging the gap between models such as USLE and CREAMS. The model has a stronger physical base than USLE and is simple and more flexible than CREAMS. The model separates the soil erosion process into two phases i.e. the water phase and the sediment phase. In the water phase annual rainfall is used to determine the energy of the rainfall for splash detachment and the volume of runoff, assuming that runoff occur whenever the daily rainfall exceeds a critical value representing moisture storage capacity of the soil-crop complex and that the daily rainfall amounts approximate an exponential frequency distribution. In the sediment phase, splash detachment is modeled using a power relationship with rainfall energy modified to allow for the rainfall interception effect of the crop. The model has been revised with new changes incorporated owing to the rise in data availability and difficulties in estimating certain parameters as in the original version. In the revised version, changes have been made to the way soil particle detachment by raindrop impact is simulated, which now takes account of plant canopy height and leaf drainage, and a component has been added for soil particle detachment by flow (Morgan, 2001).

2. Physical based models

Physically based models are based on information of the fundamental erosion processes andincorporate the laws of conservation of mass and energy (Petter, 1992). Ideally physically based models are developed to substitute conceptually distributed models because they are firmly based on understanding the physics of processes involved. The physically based models believe to be slight spatial and temporal changes of contributing factors and are more appropriate for dynamic modeling (Jaroslav et al., 1996). Examples include CREAMS, ANSWERS, WEPP, EUROSEM, AGNPS. The main restriction of these models is that they are data hungry. WEPP (Nearing et al., 1994) was developed for use in soil and water conservation and environmental planning and evaluation. Spatial distributions of net soil loss can be calculated, and spatial variability in topography, surface roughness, soil properties, hydrology and land use is taken into account (Nakos, 1983). The WEPP erosion model computes estimates of net detachment and deposition using a steady status sediment continuity equation. The net soil loss detachment in rills, i.e., rill erosion rate, is calculated for the case when hydraulic shear stress exceeds the critical shear stress of the soil and when sediment load is less than sediment transport capacity (Nakos, 1983). WEPP uses a static approach describing a steady state erosion and deposition caused by overland flow in dynamic equilibrium. However this condition is rather rare in real landscape due to relief pattern and land cover and roughness properties. Also the equilibrium in overland flow on slopes within a catchment is reached at different time (Jaroslav et al., 1996). The disadvantage of the model is that they are data demanding, so it’s difficult to reasonably get the information required running the model in a short time span.

3. Rule based expert systems

These are based on logical reasoning and structure of decision rules using information expressed in if-then form (Kadupitiya, 2002). Expert knowledge of processes occurring in watershed and survey information on topography, soil, water and cover are essential factors in these models. Rule based models reach inside the black box of the classical stimulus response model. These models receive information describing the inside environment, process that information using a set of rules, and produce a specific reply as their output. While the internal workings of many of these models are complex, the models may occupy multiple agents or sub models.

4. Hybrid approach

The hybrid approach modeling uses a combined approach through model base reinforcement with relational rule-base (Kadupitiya, 2002). Relational rules can be used to identify the physical boundaries of each entity and to classify straightforwardly up to some degree as high and low erosion risks units.

Geo-information system and erosion modeling

Soil erosion is a spatial phenomenon, thus geo-information techniques play an important role in erosion modeling. Remotely sensed data and existing maps supply a lot of data for model contribution (Petter, 1992). Data generated from RS can be linked with their spatial location for GIS applications (Yassoglou, 1989). GIS systems can deal with information about features that is geo-referenced. Generally geo-information techniques offer the following advantages in erosion modeling:(1) Fast and cost effective estimates, (2) Possibilities to investigate larger areas, (3) Greater possibilities of continuous monitoring of these areas, (4) Possibilities to refine the soil erosion model depending on the required output scale i.e. coarse global to more precise local scale. The utilize of digital elevation models and GIS offers possibilities to estimate more relevant topographical parameters. The size of a drainage basin, the mean slope, or the amount of water passing a certain point on the land surface (runoff), can be computed from a DEM (Petter, 1992).

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Types of water erosion

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Types of Erosion

Many natural phenomena cause physical erosion, which generates the transportation of the weathered elements or material of the earth surface. Erosion is the after effect of the chemical and physical weathering processes and has an interferes with the cohesion of the ground formations, leading to the formation of the weathering mantle. Erosion processes also influence human activities by causing socioeconomic, ecological, industrial and structural land use problems. The procreators that generate erosion may be discerned to natural and human.

Natural Factors causing erosion:

- Morphology
- Marine Processes
- Tectonic Features
- Climate
- Natural Disasters (e.g. fires)

Human Factors causing erosion:

- Agriculture
- Land Abandonment
- Deforestation
- Population Increase
- Urbanisation
- Tourism
- Existing Policy

Erosion is caused mainly by water and then by wind processes and human activity. Spatial dissimilarities in erosion products across different areas are due to climate, topography, hydrogeology and soil/rock characteristics. Erosion processes take place frequently at the upper soil and surface layers. The most

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common classification of erosion processes is related to the procreator factor and is the one listed below:

- Water Erosion
- Disturbance or Translocation Erosion
- Wind Erosion
- Coastal Erosion
- Landslides and Debris Flows
- Internal Erosion (provoked by groundwater flows)

The most important are wind and water erosion.

***Figure 1**: Coastal environment with both water and wind erosion present*

Water Erosion

Water erosion is best studied within the spatial context of a watershed. A small and simple watershed is composed of overland flow areas contiguous to single channel, while a large watershed comprises of smaller watersheds connected by a concentrated flow network.

The most important types of water erosion are caused by:

- Rainfall,
- Surface runoff from rainfall, and
- Surface runoff by irrigation

***Figure 2**: Raindrop impact and surface runoff from rainfall*

Among these, water flow and its course, that defines overland flow, is the most important factor to the study of water erosion. Water flows in two types of conduits; open channels and pipes. Pipe flow fills the conduit with water that flows under hydraulic pressure and takes place through the soil macropores in saturated soil. On the other hand, an open channel has a free-water surface open to atmospheric pressure, and takes place in rills, gullies and stream channels.

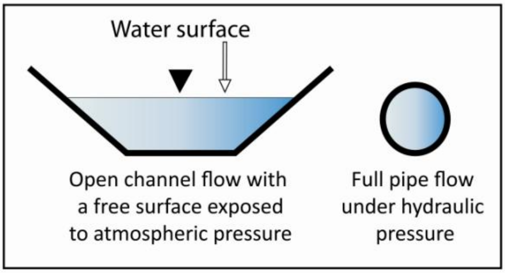

Figure 3: Types of conduits

The classification of subtypes of water erosion is based on spatial context and topographic position within a watershed, ranging in size from few square kilometers to thousands of square kilometers. The main factors affecting water erosion are described as follows.

Raindrop impact

The process known as '*Rainsplash*' is caused by the impact of raindrops hitting the bare soils that generates a shock wave, detaching particles of soil or small aggregates and dispersing them in all directions. The impact becomes more effective with the increase of rainfall intensity. For the largest drops, the final velocity may approach 10 m/s.

Figure 4: *The raindrop shockwave*

Flow traction

After *rainsplash*, the weathered material is transported by a small amount of overland water flow. This process is also known as '*Rainflow*'.

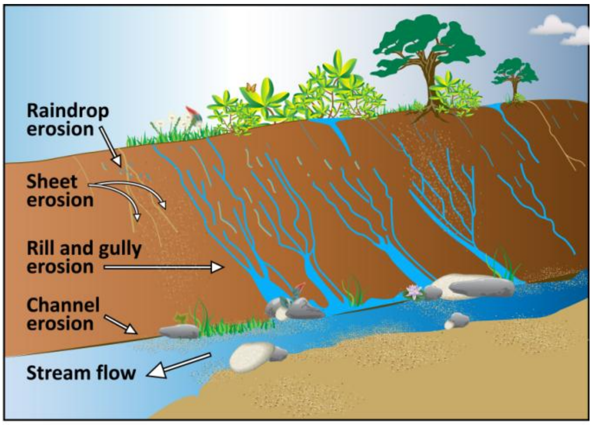

Figure 5: Types of water induced erosion

Combination of the aforementioned

The combination of *rainsplash* and *rainflow* is responsible for the creation of drainage systems which is the most important erosion factor in most landscapes across the earth. *Rainsplash* and *rainflow* processes are most significant in areas between small channels or rills, which are formed on a quickly eroding surface and are commonly grouped together as *inter-rill* erosion processes.

Runoff

The water that does not infiltrate, flows on the surface through streams, rivers or rainflow. As water flows on the surface, transports soil or land material along with it. The size of the material that is transported is relative to the slope and the speed of the flowing water.

The main water erosion types are:

- Sheet erosion,
- Interrill areas erosion,
- Rill areas erosion,
- Ephemeral gully erosion,
- Permanent, Incised gully erosion and
- Stream channel erosion.

Sheet erosion

Sheet erosion is defined as the even removal of soil from the surface and is the first phase of the erosion process with low erosion rates. When erosion becomes gradually more intense, rill erosion begins, which progresses to gully erosion, producing deeply carved channels. Interrill erosion is considered as sheet erosion as it is uniform over the interrill area.

Figure 6: *Sheet erosion*

Rills

Surface runoff is consolidated in numerous small streams of water, which are known as rill areas. Rill erosion is the erosion caused by flow that occurs in these areas. When flow is adequately intense, it entrains the soil particles directly, forming small channels or rills on the surface and erodes material by '*rillflow*', which is concentrated along these drainage lines.

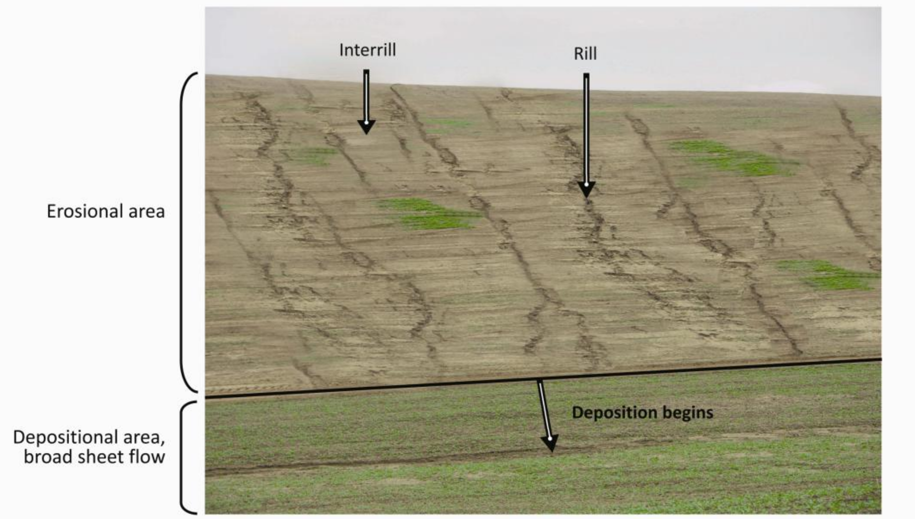

Figure 7: Erosional and depositional areas on hillslope.

The original pattern of the rivulets developed by tillage may evolve into network of rills and small channels. The location and pattern are studied by the microtopography of the soil surface on the hillslope. In theory, rills are channels that are so small that they may be eliminated by tillage. After elimination, rills have a tendency to be formed in new places. Surface runoff also takes place in rivulets on uncultivated hillslopes even if well-defined carved rills do not shape. Frequently, the pattern of surface flow is designated by plant stems and roots, debris, rocks and local depositions creating a not smooth surface, leading runoff to concentrate into small channels among the obstructions.

Interrills

Interrill areas exist between rills and the erosion that takes place on these areas is called interrill erosion. When rainfall intensity goes above the infiltration capacity of the soil on a certain area, surface runoff is developed.

The rill and interrill areas comprise the overland-flow areas of the surface and interrill in addition to rill erosion is the total water erosion that occurs on the overland flow areas of the landscape. The slope lengths of interrill areas are often short, less than one meter. Interrill areas are defined by the fact that all occurring detachment on them is caused by raindrop impact, while in rill areas it is due to surface runoff.

Gullies

When the rainfall is very heavy, and the slopes are, at least locally, steep, erosion may cause a greater opening, forming gullies of significance depth (>1.5 m) and width. If a new intensive rainfall occurs, the pre-existing gullies are going to become flowing streams and the water, charged with soil material is going to form a debris flow that builds up a high kinetic energy able to generate intense erosion and damages across the gully.

***Figure 8**: Gully at Somogy County, Hungary*

1. **Ephemeral gully erosion**

Ephemeral gullies are usually developed within areas of the size of a field, where farming and related land-disturbing actions take place. Ephemeral gully erosion is a feature unique to cultivated fields. Flow in concentrated-flow areas erodes rapidly the surface soil layer and reaches the resistant soil beneath. Erosion widens rather than deepens the channel.

The quantity of sediment produced by this type of erosion equals the quantity of sediment produced by interrill and rill erosion in the same field. In farm fields, ephemeral gullies are crossed as a part of routine farming operations and are filled routinely by tillage operations, which remove soil from the overland-flow areas adjacent to these channels.

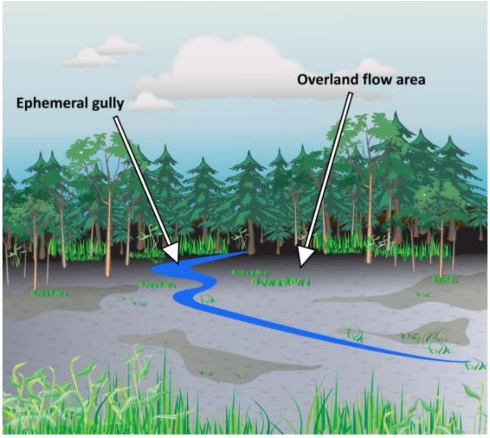

***Figure 9**: Blending of ephemeral gully areas with overland flow areas*

The macrotopography of the surface characterised by ephemeral gullies, is responsible for theirreformation in the same location after refilling by farming operations. Through time, gullies gradually become blended with the hillslopes rather than remaining incised with vertical sidewalls. This periodic refilling and reformation by erosion is the reason they have been named *ephemeral gullies*.

When soil is loosened because of tillage, the remaining soil layer in the ephemeral gully area is much more erodible than the untilled soil directly underneath the tilled zone. Water flow rapidly erodes the ephemeral gully to the depth of the non erodible, untilled layer, and then it erodes the side-walls of the gully, creating a wide, shallow channel with a high width-to-depth ratio.

2. **Permanent, incised gully erosion**

Erosion in permanent, incised gullies is episodic, varying from year to year. Permanent gullies normally are incised channels that are wide and deep relative to the flow in them. Permanent, incised gullies commonly are recent in age and are developed in just a few years. They also appear on natural but also on disturbed areas, which are defined as channels that are too deep to cross or to fill with normal farming activities. The progress of a gully into a field causes serious damages and gives high sediment loads.

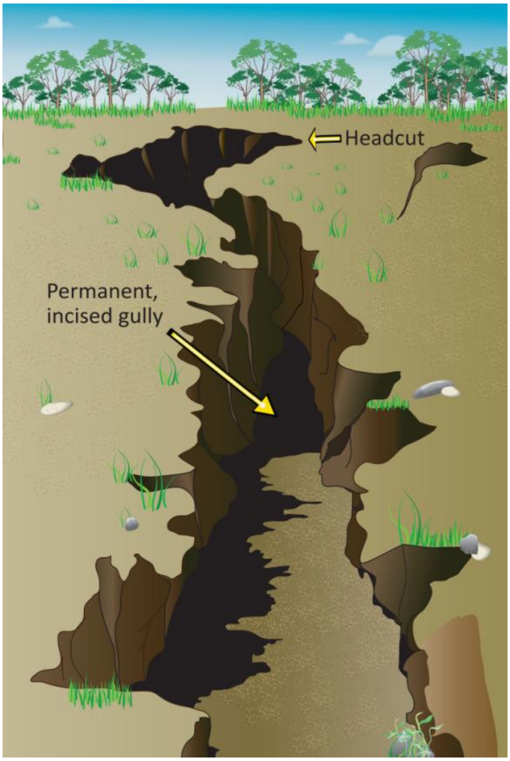

Figure 10: *Permanent, incised gully in an agricultural field*

Stream channel erosion

Stream channels are an important part of the landscape when developed in the absence of human activities. However, human activities on upland areas and within channels may be of great significance to the stream-channel erosion. Channel features, along with grade and meander form, are the midstream modulating the flow and sediment load delivered to the channels from the upland areas. Thus, any changes in land use modifying runoff and sediment delivery may produce changes in the stream channels, which may be changing constantly by nature, but the change in stable stream channels can be almost imperceptibly slow.

On the other hand, unexpected changes in land use, like forestry to urban use or forestry to intensive agriculture, may increase upland runoff considerably and destabilize stream channels starting channel erosion, through widening of the channels, forming of headcuts that migrate upstream rapidly, producing large sediment loads and degrading the stream quality critically. The most energetic locations of stream-channel erosion generally occur on the outside of meander bends, where channel bank may move back several meters during intense storms.

Finally, some measurements for controlling channel erosion may be:

- the decrease of runoff rates with impoundments,
- the construction of enlarged channel cross sections,
- the installation of grade-control structures in the channel, addition to bank protection and,
- the placement of in-stream vanes to divert flow away from channel banks.

One simple way to calculate channel shape, is the width-to-depth ratio. For example, for a narrow channel the width-to-depth ratio is expected to be small (e.g., 1:1), while for a wide channel it exceeds 10:1 and for sheet flow it is countless. The drainage channels development is the physical evolution of the landscape. Areas between channels and the watersheds outline the channel's drainage basin.

Snowmelt erosion

Snow may be another significant erosion factor. In northern parts of the Earth where snowfall is dense, during early spring when the snow melts, the resulted erosion is intense. In these areas, the frozen soils during winter constrain infiltration increasing surface runoff and consequent erosion. Surface conditions may differ from an ice and snow-covered surface to a defrosted surface with frozen subsoil. The impregnate soil shows low shearing force and high erodibility, while high losses may occur when snow melts or when rain falls on partly frozen ground with thawed topsoil. In cases of heavy rainfall, the result will be rill and gully formations.

Erosion by overland flow resulting from snowmelt depends on a particular combination of factors. If snowmelt runoff starts when the soil is thawing, erosion may be considerable. If there is rainfall on thawing soil, it will cause very high rates of rill erosion, because the soil is highly erodibleand the rainfall although low, is steady producing very low runoff rates.

Bank erosion in rivers and lakes

This extreme type of erosion occurs only in constrained places, specifically, in river valleys and along lake shores. After an intense rainfall the volume of water increases, causing consequentlythe raise of the water level in the drainage channel and the increase of the speed flow, resulting to the fast undercutting of the banks, the collapse of the upper part of the bank soil and the change of the river's path. Thus, bank erosion may be stronger by quick runoff after an intense rainfall.

Erosion by piping

Water frequently flows through the soil just below the surface, which may contain macropores, other small openings and channels left by decaying roots, burrowing insects and animals, which may become pipes, and pipe flow may erode soil, causing a type of erosion known as piping. Initially, the diameter of the pipes is quite small, namely few millimetres, but when erosion occurs, they may be enlarged to diameters up to one meter. When a pipe is near the surface, the roof of the pipe may fall down, leaving an open rill or permanent, incised gully.

***Figure 11**: Erosion from simple pipe diversion*

Disturbance or Displacement Erosion

Tillage erosion

Plowing, either tansverse to hillslope or along the contours is responsible for a type of erosion known as tillage erosion. During plowing, soil transport occurs in both cases, but plowing transverse to contours causes 1,000 times bigger soil transport. The main factors that affect tillage erosion are the morphological slope change, the management scheme and the tillage type.

Land levelling

The mechanical soil removal in order to alter the surface slope for agriculture, using bulldozers causes this type of erosion.

Soil lack due to harvest

Moreover, during mechanical and manually harvest, soil removal takes place causing erosion.

Erosion due to animal living

The animals' hoofs may destroy vegetation when grazing by the pressure applied on surface, leaving a nude pedologic surface, susceptible to water erosion.

Erosion by irrigation

When irrigation water is applied to the land by overhead sprinklers, or subsurface emitters erosion is not a problem. When irrigation water is applied with surface-applied systems erosion may be important, because surface water is introduced at the head of furrows to flow down the field and infiltrate into the soil. This irrigation system produces large erosion rates, especially at the upper ends of the furrows, where erosion rate may be four times the average erosion rate for the field.

Overland and concentrated flow areas on a landscape

Sediment yield is the measure of average net erosion for the watershed and is calculated as the sum of the sediment produced by all erosional sources (counting that from overland flow, ephemeral gully, permanent, incised gully and stream channel areas) less the amount of sediment deposited on these areas and on the valley floodplains.

Erosional and depositional areas on a hillslope

Erosional and depositional areas may be recognised for hillslopes with concave segments on which deposition takes place. Soil loss, which defines net erosion, takes place on the upslope part, whereas net deposition takes place on the downslope part of the hillslope. The amount of sediment that is lost from the depositional section of a hillslope is less than the soil loss from the erosional section. The erosional area is the entire length of consistent and convex-shaped hillslopes, and the quantity of sediment leaving these hillslopes equals the soil loss. Moreover, on hillslopes with only slight concavity, net deposition does not take place and the amount of sediment leaving the hillslope also equals the soil loss.

Hillslope shape does not induce deposition, but dense vegetation and other barriers that slow runoff dramatically, may induce deposition on any slope shape.

Figure 12: *Cases where deposition on slope change may be induced*

The rainfall amounts, as well as slope degree, control the erosion rates. As a consequence of the slope degree effect, for rainfall less than 20 mm, the runoff and sediment transportation in the gentle slope is higher, but for rainfalls above 20 mm, it is the steeper slope which has greater sediment transportation.

Erosion is maximum at the rill-interrill boundaries. The sediment concentration/ precipitation relationship may be drawn as an envelope curve demonstrating that any rainfall event of a given amount and intensity, has a maximum runoff sediment concentration limit, which is interpreted to be a function of the runoff sediment transport capacity, depending mainly on the slope steepness.

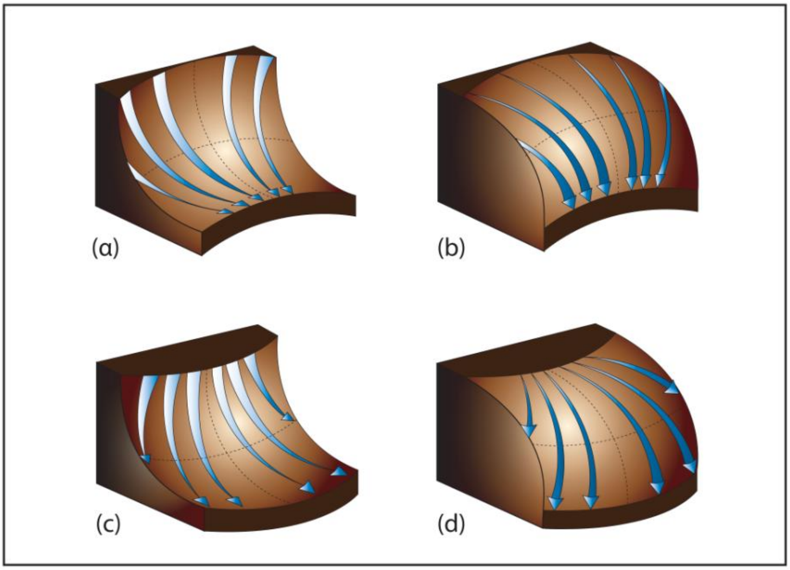

Figure 13: *The influence of curvatures and geometric forms of relief on mass flows: (a) concave-concave form, (b) convex-concave form, (c) concave-convex form, (d) convex-convex form.*

GIS tools for erosion studies
Development of Erosion Risk Index Map
Case study: Tinos Island, Cyclades, Greece

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Geographical setting

Tinos is the third largest island of the Cyclades after Naxos and Andros and covers an area of 194.8km^2. Geographically the island belongs to the central Cyclades and is located south-east of Andros and north- west of Mykonos. Geographically it belongs to the central Cyclades.

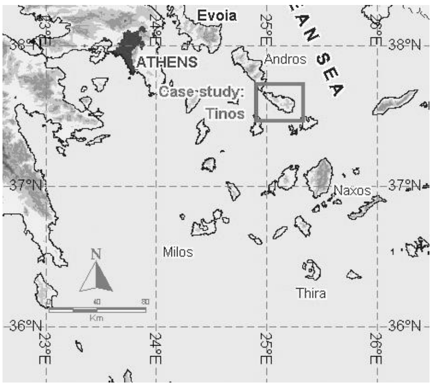

Figure 1*: The location of the study area.*

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Climatic Conditions

The climate of the island is temperate (Theocharatos, 1978). The air temperature has lower values along the central Cycladic islands Andros – Tinos – Milos – Naxos. During the arid period, Tinos is more humid than the rest of central Cyclades, while in the humid period the precipitation is more than 100mm. Snow is very rare in the study area. Relative humidity over Tinos fluctuates between 65 and 70%. The prevailing wind during the year is northerly. The most common direction is the Etesian northerly and north-easterly wind that prevails in the Aegean Sea with increasing frequency and intensity during the summer (Theocharatos, 1978).

Geological setting

Tinos Island belongs to the geotectonic unit, known as Atticoclycladic complex (Melidonis, 1980). Three sequences of rocks participate in the geological structure of Tinos:

1. the sequence of metamorphic rocks, which dominates and takes up 79% of the total area of the island,
2. the sequence of igneous rocks and
3. the quaternary sediments.

The existence of three main categories of folds, with axes of NW-SE, NE-SW and N-S directions and two groups of faults with SE-NW and NNE-SSW directions, complete the geotectonic structure of the island.

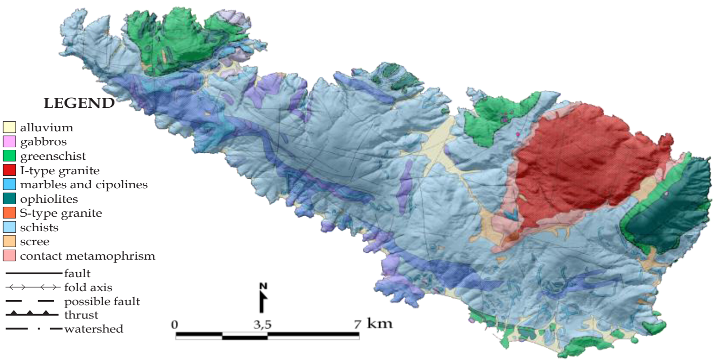

***Figure 2**: The geological map of the study area.*

Geomorphological setting

The morphology is controlled mainly by the extent of lithologic formations and the tectonics, together with the climatic characters. The high humidity and the strong NNE winds cause intense chemical alteration and weathering on schist and granite. Human activity is another important factor that affects the morphology of the island. This activity is consisted by the construction of artificial terracettes, which cover a large part of the island's surface, keeping the soil in place, and thus preventing it from erosion phenomena.

The island is characterized as semi-mountainous. Flat sections are plotted mainly in the discharge of the valleys; Komi-Kolimpithra's valley is a remarkable example.

Characteristic of the island is the intense asymmetry between the SW and NE part on both sides of the main watershed along the island, which coincides with the fold axis and separates the island in two regions with different forms of low relief, is characteristic (Livaditis & Alexouli-Livaditi 2001).

During the Miocene, the rise of plutonic rocks, as well as the consequent tectonic movements, indicate that the development of the relief occurred in a relatively short time interval under specific climatic conditions.

Livaditis & Alexouli-Livaditi (2001) has distinguished three morphological units with different relief types can be distinguished:

1. the first unit which covers the biggest part of the island,
2. the second unit which is present at the two ends of the island, and
3. the third unit which is found at the eastern part of the island and is characterized by granitic weathering forms.

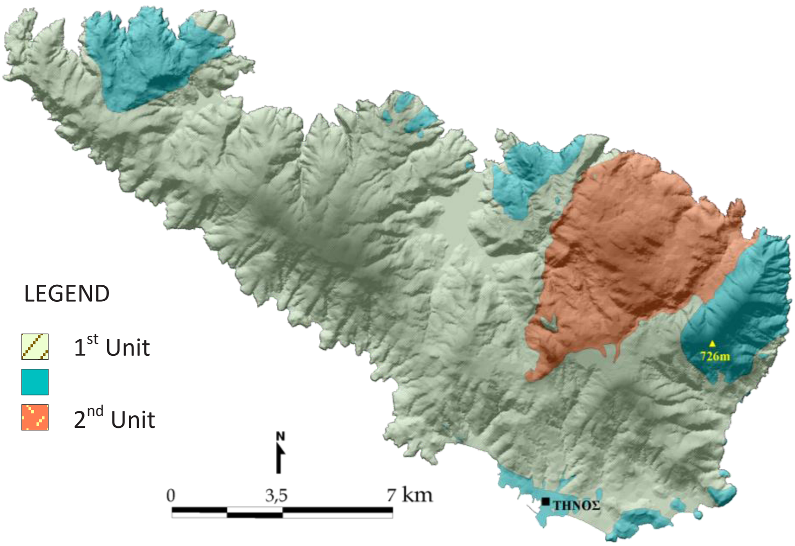

***Figure 3**: Morphology of Tinos Island.*

The description of the most important geomorphological formations that were mapped on the Island of Tinos follows (Leonidopoulou 2008).

Tafoni and Alveoles. These formations are developed along rock's discontinuities where porosity is higher and rock's strength reduced.

In some cases, intense deep erosion takes place in Tinos. This type of erosion is linear, directly connected with the movement and the amount of water discharged from the drainage network.

Another important geomorphological characteristic is peneplains. These formations are developed as a result of erosion processes, creating a layer of soil on their surface, which in combination with the reduced angle slope of the peneplain surfaces, less than 10°, facilitate infiltration, leading to the development or the enhancement of the aquifer.

Tinos' drainage network comprises from 170 torrents of seasonal mainly flow. Form them 89 torrents are Ist order, 62 are IInd order, 15 are IIIrd order, 3 are IVth order and only one is Vth order. Entirely, it consists of 632 Ist order streams, 158 IInd order streams, 31 IIIrd order streams, 6 IVth order streams and only one Vth order stream.

Erosion risk maps

The development of erosion risk maps involves a series of different stages, as field work, air-photo stereo-observation, digitization of geological, topographical and drainage system maps, definition of the input and output variables, establishment of logical rules between the input and the output variables, analysis and visualization of the results.

The principal variables used in this work will be:

1. erodibility of the rocks,
2. slope gradient of the morphology,
3. drainage density, and
4. land use

The erodibility variable is very complicated as it depends on the physical and chemical composition of the rock and the existence of major (folds, faults) and minor (bedding, foliation and joints) tectonical structures. Generally, the erodibility of the rock depends on the lithology, the process involved and the protective mechanisms. Lithology is connected to the hardness of the rocks and the resistance to erosion. This variable is difficult to be directly measured. Erodibility is a function involving rock's hardness, permeability and infiltration capacity. Marbles and blueschists are considered to be more resistant to erosion, while alluvials, soil and weathered mantle more prone to erosion.

The second variable that has been processed is the morphological slope gradient of each drainage basin. Apart from the slope gradient, form (convex, concaves), aspect and extend are also important factors. It is obvious that slope steepness is critical to the erosional intensity.

Drainage density input variable (ratio of the total stream lengths to the drainage basin's area) which is highly related to water's runoff quantity and substratum's permeability. In general, drainage density is high at basins of weak impermeable rocks and low in basins of resistant and permeable rocks. It was found that drainage density increases according to basin's average slope (Gregory & Wallig, 1973). Furthermore, drainage density of rills is highly related to slope gradient (Schumm, 1977).

As far as land use is concerned, erosion occurs in exactly the same way on all land uses and is related directly to the forces applied to the soil by the erosive agents of raindrop impact and surface runoff in relation to the resistance of the soil. Land use and land-use activities affect both the forces applied to the soil and the resistance of the soil to those forces. Ground or surface cover is material in direct contact with the soil that protects the soil from raindrop impact and slows surface runoff. The effect of ground cover on erosion is related directly to the percent of the surface covered. The effect of ground cover varies among climate, topography, and soil conditions.

The first step of this study is the digitization of the geological and topographical maps, scale 1:50.000 and the interpretation of aerial photos in scale 1:33.000. The study of the above mentioned elements is focused on the recognition, definition and impression of the factors which affect the erosion risk.

The aim of this first collection of data is the development of a geomorphologic map, which is enriched through fieldwork during which GPS is used. Through GIS analysis of primary and secondary data new information layers are extracted. Logical rules are imported via mapbasic programming language into GIS MapInfo Professional and are formulated into different weight parameters which affect the erosion risk index (Table 1). Finally, thematic maps are developed, presenting the geographical distribution of each parameter, as well as the final output index of the erosion risk index.

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GIS tools for erosion studies. Development of Erosion Risk Index Map Exercise

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We selected five torrent examples on Tinos Island in order to develop an erosion risk maps for every drainage basin. The selected torrents for this exercise are IIIrd and IVth order and are developed on areas with variety of geomorphological landforms.

The Falatados-Livada drainage system, located on the NE part of the island, is developed along the lithological contact of granites and schists.

The Alfareti drainage system, located on the N-central part of the island, is developed mainly on the schists.

The Rochari drainage system, located on the N-central part of the island, is developed on schists.

The Panormos drainage system, located on the NW part of the island, is developed on schists and marbles, found at a 10km radius around the torrent's mouth.

The Tinos drainage system, located on the SE part of the island, is developed mainly on schists.

1. Develop the logical rules that you will use to derive the erosion risk index (Table 1).
2. Develop a thematic map presenting the values' geographical distribution of the rocks' erodibility of the study area.

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3. Develop a thematic map presenting the values' geographical distribution of the morphological slope gradient of the study area.
4. Develop a thematic map presenting the values' geographical distribution of the drainage density of the study area.
5. Develop a thematic map presenting the values' geographical distribution of land uses of the study area.
6. Develop a thematic map presenting the values' geographical distribution of erosion risk map index of the study area.

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Table 1. The logical rules used to derive the erosion risk index.

If	ERODIBILITY	is		&	SLOPE	is	High					Then	Erosion Risk Index	Is	High
If	ERODIBILITY	is	High	&	SLOPE	is	Medium	&	Drainage Density	Is	High	Then	Erosion Risk Index	Is	High
If	ERODIBILITY	is	High	&	SLOPE	is	Low					Then	Erosion Risk Index	Is	Medium
If	ERODIBILITY	is	Medium	&	SLOPE	is	High					Then	Erosion Risk Index	Is	Medium
If	ERODIBILITY	is	Medium	&	SLOPE	is	Medium	&	Drainage Density	Is	High	Then	Erosion Risk Index	Is	Medium
If	ERODIBILITY	is	Medium	&	SLOPE	is	Low	&	Drainage Density	Is	High	Then	Erosion Risk Index	Is	Low
If	ERODIBILITY	is	Low	&	SLOPE	is	Low					Then	Erosion Risk Index	Is	Very Low

(adopted by: Gournelos, Vassilopoulos, Evelpidou, 2001)

Soil Conservation Measures: classification and description

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SOIL CONSERVATION MEASURES: WHY AND WHAT FOR?

The aim of Soil Conservation

Before going into the detail of Soil Conservation Measures, some preliminary questions must be considered, for sake of clarity either in formal terms or in the substantial ones, which, actually, justify the extent and in-depth approach to such topic.

As Morgan (2005) states:

"The aim of soil conservation is to reduce erosion to a level at which the maximum sustainable level of agricultural production, grazing or recreational activity can be obtained from an area of land without unacceptable environmental damage." (Morgan, 2005:152).

The core elements of his statement deserve ttentive consideration and they are:

- reduce soil erosion

  Not prevent (as soil erosion is a natural phenomenon it is not a matter of stopping it)
- to a [certain conditioned] level

  Soil loss tolerance (a central operational concept in soil conservation, addressed to later)
- obtain maximum activity output

  Resources are to be explored (as resource means a good valued by its potential or actual use).
- in a sustainable way

  Resources are not to be exhausted (as the need of such goods keeps existing and sometimes even increases).
- without unacceptable environmental damage

  Impacts kept controlled (again the sustainability issue, not only but also).

N. Evelpidou & T. de Figueiredo (eds.) *Soil Protection in Sloping Mediterranean Agri-Environments: lectures and exercises*. Instituto Politécnico de Bragança, Portugal, 2009

Soil Loss Tolerance

Soil loss tolerance is a central operational concept in Soil Conservation. It defines the limit up to which soil loss rate is acceptable for the systems under consideration and the conditions set above (productivity, sustainability, and minimal environmental impact).

In theory, soil loss rate should be at most equal to soil formation rate, in order to ensure that the balance of particles is never negative in a certain placed and through time. The problems in defining soil formation rate are, however, manifold. Conceptual and practical discussions may be undertaken when addressing to the rates that should better represent soil formation rate: rate of weathering, rate of weathering front progress, rate of soil deepening (singly or combined).

Discussions apart, referenced values of soil formation rates ranges from 0.01 to 7.7mm equivalent soil depth per year. An average value of 0.1mm y-1 can be assumed and this approximately corresponds to 1t ha-1 y-1.

In practice, maximum permissible soil loss rate that maintains soil productivity in the medium to long term also depends on the possibility to increase soil depth and keep soil productivity at acceptable level through agricultural practices. As so, soil loss tolerance may vary and experience recommends (T is soil loss tolerance):

- Deep soils, developed on unconsolidated parent material – T = 11t ha-1 y-1 (10 is better!)
- Shallow soils, over hard parent material – T = 2t ha-1 y-1

The two thresholds mentioned (2 and 10t ha-1 y-1) are helpful to define classes of actual erosion risk. In fact, below the latter, all soils, shallower or deeper, are losing soil at an acceptable rate, meaning that erosion risk is low. Above the former, even the deeper soils are losing material at a rate higher than acceptable and, therefore, there is a severe erosion risk threatening soil. Between the two, erosion risk may be considered globally moderate, because for shallower soils it is high but for the deeper ones it is low.

PRINCIPLES OF SOIL CONSERVATION

What Soil Conservation measures should be

Application of soil conservation is a very practical issue and, performed under a variety of situations, not always easily or entirely seized. As so, or because of this, some basic principles must be considered in order to allow the intended purposes to be successfully attained, in any practical condition. Selection of soil conservation measures should then be a very locally oriented procedure, but always performed in respect of a certain set of principles.

Hence, soil conservation measures should be:

- adequate
  Focused on the problem(s) and process (es) identified
- effective
  Able to control the problem as predicted
- integrated
  Part of the activity regular practices
- feasible
  Account for local labour and economic conditions
- accepted
  Perceived as an improvement

The two first fall under the technical side of soil conservation whereas the remainders are part on the socio-economic approach to the problem. This means that, even though soil conservation should start as a technical matter, and this is the scope of the lecture, in no way social and economical issue should be kept apart from the solution when dealing with soil conservation implementation.

As soil conservation measures should be adequate and effective, and because soil erosion is the problem to be tackled, processes involved have to be identified at first. It can be readily perceived that different measure address differently to different processes. Therefore, to meet adequacy and effectiveness required, selection of soil conservation measures has to carefully consider processes acting in the field. The survey of evidences and or rates of processes and their spatial distribution is obviously required, too.

Table 1. Soil conservation measures: effectiveness in controlling erosion processes

Practice		Rainsplash		Runoff	
	Specific	Detachment	Transport	Detachment	Transport
		Control of prcess			
Agronomic measures	Covering soil surface	strong	strong	strong	strong
	Incresing surface roughness	no	no	strong	strong
	Incresing depression storage	moderate	moderate	strong	strong
	Increasing infiltration	no	no	moderate	strong
	Fertilizers	moderate	moderate	moderate	strong
	Tillage	no	no	strong	strong
	Subsoiling, drainage	no	no	moderate	strong
Mechanical measures	Contouring, ridging	no	moderate	moderate	strong
	Terraces	no	moderate	moderate	strong
	Waterways	no	no	no	strong

(adapted from Morgan, 2005).

Classification of soil conservation measures

Soil conservation measures are of very different types. A fully consistent classification of measures is hard to reach and so, classification schemes may fail at some point to adequately accommodate any existing or newly designed measure.

One classification scheme commonly adopted, even though some variations may be found from author to author, considers the object and the material focus of measures of as a criterion.

- Soil Management

  Accounts for soil conservation measures addressing to improvements in soil resistance to erosion
- Vegetation (crop) management

  Accounts for soil conservation measures addressing to improvements in soil protection by vegetation cover
- Mechanical / Structural methods

  Accounts for soil conservation measures addressing to changes in topography and runoff paths

From the first to the last, there is an increase in implementation complexity, regarding the level of change in actual conditions and practices, as well as in the level of investment required to carry them on. From the first to the last, again, the number of processes controlled and the effectiveness of control achieved generally increases. This is due not only to the effectiveness each one of the measures per se, but results also of the imperative combination with other measures from more than one of the above categories. All together, the elements carried to discussion help explaining the recommendation of the first to almost any situation where erosion control is required, but a much more selective recommendation of the other, especially the structural methods, following increasingly severe erosion risk.

To illustrate this it can be said that conservational tillage methods should be a common practice in land under any erosion risk severity. On the contrary, only when erosion risk is very severe should structural measures be applied as terraces and these imply important changes in the landscape, I the land use model and in cultivation practices that normally come together with the implementation of other conservation measures, eg contour tillage. Furthermore, such change, and the investment required to perform it, can only be justified under conditions of very severe erosion risk.

A very schematic description of soil conservation measures is provided in the following sections, according the classification indicated above.

Soil management

Soil management measures account for improvements in soil intrinsic resistance to erosion. This can be achieved promoting structural stability or limiting structural degradation. The former focus in improving general structural conditions associated with biological activity and organic matter (organic fertilization), in increasing particle binding (stabilizers), in allowing moisture conditions that favour natural process of aggregation (drainage). The latter focus on tillage, as tillage is the main cause of soil disturbance in cultivated areas.

- Organic matter (Fertilization)

  Broadly fertilization or specifically organic matter management, through addition of residues or organic fertilizers to soil, enhances biological activity and improves soil structural condition.

- Tillage

  Tillage comprises practices and operations that are an integral part of the history of agriculture, since its very beginning. Traditional agricultural systems persistently included tillage as routine practice. Mechanization of tillage operations hugely increased degradation processes rates and extent. This, combined with the need for an efficient use of energy (due to the rise of energy cost), helped devising new tillage procedures and systems broadly labeled as conservation tillage. They are less disturbing for soil, they are cheaper as they are less energy consuming, they are more environmental-friendly, with no less crop productivity.

  Actual types of tillage systems are briefly described below:

  - Conventional tillage

    Traditional plowing is not considered a conservative soil management technique. It implies arable soil reversion as plow passes and, traditionally, this was performed more than once a year. Soil disturbance is highest among tillage systems and this, summed to the traffic of tractors and trailed implements in fields, outcomes serious structural degradation and compaction.

    In any case and in this one it is more than justified to carefully consider actual soil moisture at time of tillage. In fact, the friable cohesive sate of soil consistency is the best one for tillage.

  - Contour Tillage

    Contour tillage is the first step towards conservation tillage. It consists of tillage operation on contour, thus increasing surface roughness. This allows higher surface water detention during rainfalls, and so runoff and particle entrainment along the slope is reduced.

  - Conservation Tillage

    Some definitions help describing techniques under this heading.

    - Conservation agriculture

Crop residues are kept over ground, at least over 30% of the surface (where water erosion is major threat) or at an annual rate of 1100 kg ha-1 stubble (where wind erosion is the major threat).

- Minimum tillage

Tillage operations prior to seedling are performed with chisel, scarifier, etc. Weeds are controlled by tillage or by low environmental impact herbicide. In the former case, the soil is not entirely reverted and tillage is performed soon after harvest, in order to incorporate and trigger germination of seeds (weeds and prior crop), thus providing soil cover during inter-crop period.

- Ridge / Strip tillage

No soil disturbance between previous harvest and new seedling, except nutrient injection on strips. Seeding equipment operates in weed cleared ridges, stubble being kept between plant rows. Ridges may be built up and seedbed prepared by several types of implements. Weeds are controlled by hoe-type implements or by low environmental impact total herbicide in prior to seedling or emergence.

- No tillage (direct-seedling)

No soil disturbance between previous harvest and new seedling, except nutrient injection on strips. Seeding equipment have specific implements that remove or cut stubble, open a rill in the soil surface and cover the seeds dropped in. Harvest must leave crop residues fairly distributed over ground. Weeds are controlled by low environmental impact total herbicide in prior to seedling or emergence. Exceptionally tillage may be performed for weed control. Better system for annual crops.

- Drainage

Drainage is important for soil conservation mainly for two reasons. Lowering soil moisture allows drier antecedent conditions when rainfalls occur and this may delay overland flow generation as higher soil water intake rates are possible. On the other hand, structural stability decreases as moisture increases (in the range of soil moisture addressed to here), increasing particle availability for entrainment.

- Soil stabilizers

These are substances or materials applied to soils in order to increase binding opportunity and strength among soil particles. Due to price and offer scarcity, their use is limited to small green areas and gardens.

Several types of soil stabilizers are found, such as: (i) Organic by-products; (ii) Polyvalent salts (gypsum); (iii) Synthetic polymers (polyacrilamide).

Actually, all but the last soil management conservation measures are or should be part of the regular practices in agricultural land, as appropriate agronomic measures.

Vegetation (crop) management

Vegetation or crop management measures account for improvements in soil surface protection by plant or plant residue cover. Protection provided by plant or residue cover reduces rainfall kinetic energy and thus the erosive power of raindrops hitting the surface. Vegetation intercepts rainfalls and, therefore, contributes to sharply increase actual water intake rate of soils because the rate at which effective rains reach the soil surface is much lower when compared with actual rainfall intensity. The former is generally such as to infrequently exceed soil infiltration rate. The probability of excess rainfall to be formed decreases as vegetation cover increases. If that happens, runoff is occurs and may flow along the slope. Again, crop or vegetation management contributes to protect soil from particle entrainment by overland flow and to limit erosive runoff generation or effects as it is the case of conce3ntrated runoff and gullying, respectively. In fact, stems, residues and surface roughness induced by the vegetation itself or by crop management operations, sharply reduce eha probability of occurrence of such processes. Moreover, indirect effects of practices concerning conservation crop management contribute to enhance soil intrinsic resistance to erosion, either through aggregate stability improvement or through infiltration rate increase.

In this section, the list of conservation measures considered under vegetation or crop management is simply indicated. Student is strongly encouraged to follow image descriptions presented in actual lecture and to find in literature recommended the literal description also provided during actual lecture. Morgan (2005) is the base reference.

An attempt to group measures according to the focus and context of their application is performed below:

- Measures strictly concerning cropland
    - Measures addressing to vegetation distribution in time and space
        - Rotation (the classic but also shifting cultivation, row-crop cultivation, grazing and forest land management)
        - Cover crops
        - Multiple cropping

        - High density planting
        - Strip-cropping (a specifically designed soil conservation measure)
    - Measures addressing to residue cover
        - Mulching
- Measures concerning degraded sites or marginal land
        - Revegetation (gullied areas, landslide scars, embankment and cut slopes, afforestation, pasture land, recreational areas
- Measures concerning integrated management areas
        - Agroforestry

Mechanical / Structural methods

Structural measures are meant to control runoff generation and distribution along slopes, and to minimize its erosive power or capability to transport soil particles. Normally structural conservation measures are limited in their application to areas where runoff and soil entrainment are likely to occur frequently and / or at high rates such that erosion damage, on- and off-site, is severe. More simply stated, structural measures should be applied to areas were severe erosion risk exists. Measures coping with specific problems such as severe and permanently gullied sites and steep cut slopes are also account for under the present heading.

In this section, as in the previous one, the list of conservation measures considered under structural measures is simply indicated. Student is strongly encouraged to follow image descriptions presented in actual lecture and to find in literature recommended the literal description also provided during actual lecture. Morgan (2005) is the base reference.

An attempt to group measures according to the focus and context of their application is performed below:

- Measures addressing to topographical reshape
    - Contour bunds
    - Terraces
- Measures concerning runoff control
    - Waterways
- Gullycontrol
- Slope stabilization (structures, geotextiles)

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Soil Conservation Measures: Exercises

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Foreword

Exercises proposed under the topic of Soil Conservation Measures addresses to the design of structural measure, namely waterways in the context of a soil conservation plan. However, to get a better insight on the actual meaning of soil loss as a resource loss, a prior exercise is proposed to students. It concerns calculations of soil loss due to sheet (interrill) erosion and to gully erosion, and allows the perception through realistic number of the impact of these mechanisms on soil resource.

<u>HOW MUCH DO WE LOSE WHEN WE LOOSE SOIL?</u>

Sheet erosion

A soil, characterized as presented below, suffers soil loss by water erosion estimated as 12 t/ha per year.

a) Calculate annual soil depth removal by erosion

b) Calculate annual loss per hectare of the following constituents: clay, organic matter, Nitrogen

c) Calculate loss in soil water storage capacity, after 10 years under such soil loss rate

d) Comment on results

Bulk density: BD = 1,2

Organic matter: %OM = 2,5% (Com = 58%; Nom = 5%)

Rock fragment: %RF = 15% %

Clay = 20% %

N. Evelpidou & T. de Figueiredo (eds.) *Soil Protection in Sloping Mediterranean Agri-Environments: lectures and exercises*. Instituto Politécnico de Bragança, Portugal, 2009

Effective depth of arable soil: z = 30cm

Water content at Field Capacity (pF 2,0): %Hcc = 30%

Wilting point (pF 4,2): %Hcc = 12%

Gully erosion

After a heavy storm, a gully incised a 2ha field. All along the 70m gully, measurements were taken every 10m frm head to end of gully: depth, width at surface and shape o cross section. Results are presented in Table.

Fill in the blank cases in Table, performing the appropriate calculations.

Show calculations and comment on results.

Table 1. Gully field measurements and calculation of volume eroded (T – Triangular; R – Rectangular)

Gully Section/Part		Distance (m)	Gully (cm)		Form of cross section	Area of cross section (cm2)	Volume of part (m3)
			Depth	Width			
-	Head	0	-	-	-		
1		10	10	10	T		
2		20	15	20	T		
3		30	25	40	R		
4		40	40	70	R		
5		50	45	80	R		
6		60	50	80	R		
7	End	70	50	85	R		
Gully Total Volume (m3)							
Total Loss per unit area, volume (m3/ha)							
Total Loss per unit area, weight (ton/ha)							

<u>HOW DO WE CONTROL SOIL LOSS</u>

Design of waterways in the context of a soil conservation plan

(Application of methodology proposed by Morgan 2005)ully erosion

Read the text provided in class, regarding directly the design of soil conservation structural measures, such as terraces and waterways (Morgan 2005).

Explore the example detailed for water ways.

Basic formulas are:

Manning – $v = (1/n)\ r^{2/3}\ s^{1/2}$

Discharge – Q = v A
v – flow velocity (m/s)
r – hydraulic radius (m) (cross sectional wetted area / perimeter)
s – slope (-)
n – Manning friction factor
Q – discharge (m^3/s)

Consider the procedures explained in the example in the text provided and apply them to the following conditions and scenarios:

a. Conditions

Waterway:

Slope – 1,5%

Clay loam soil

Medium grass cover with height – 4cm (Bermuda)

Drainage area:

Square shape

Area 60ha

1/5 – Forest over shallow soil in steep slope

30% - Scrub over shallow soil in rolling area

½ - cultivated area over loam soil in moderate slope area

Design storm:

Consider a 10 return period of temperate type of precipitation

b. Scenarios

1) The above
2) Waterway bed with very good grass cover with height – 10cm (Bermuda) and 0,5% slope
3) Waterway bed made on soft rock, non vegetated and 1,5% slope
4) 50 year return period of precipitation

Comment on results, interpreting scenarios and comparing results.

References

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Cost-Benefit Analysis for Land and Water Management

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The term evaluation is used for a wide array of activities. Here it is used as a project management tool for project management and policy makers to assess the 'output' and the 'impact' of development activities. The output does not have to be confined to physical effects. **Evaluation** has been defined as a process for determining systematically and objectively the relevance, efficiency, effectiveness and impact of activities in the light of their objectives (UN, 1984).

Effectiveness of the project is comparing objectives and results and **efficiency** is comparing costs and benefits. With the **impact** of the project one focuses on the effects of the project on the welfare of the community. For soil and water conservation it is important to clearly define that community, since it could include various groups upstream and downstream and within present and future generations.

An evaluation can either be carried out prior to certain activities (an ex-ante evaluation or appraisal), during the implementation of the activities (e.g. mid-term evaluation, monitoring) or after completion of the activities (ex-post evaluation).

Project evaluation in a strict economic sense refers to the analysis of the financial and economic aspects. It is then assumed that the other aspects (e.g. technical, commercial, social, ecological) have been adequately considered in the project preparation stage.

Application of CBA

In practice cost-benefit analysis consists of impact analysis, followed by the valuation of the various impacts. It eventually aims at a comparison between the present value of the streams of benefits (positive effects) and the present value of all investment and recurrent costs (negative effects).

All direct, indirect and external effects must be incorporated in an impact analysis, and attention has also to be paid to intangible effects such as human life, historical sites or natural beauty.

The general sequence of analytical steps in cost-benefit analysis (CBA) includes:

N. Evelpidou & T. de Figueiredo (eds.) *Soil Protection in Sloping Mediterranean Agri-Environments: lectures and exercises*. Instituto Politécnico de Bragança, Portugal, 2009

- determination of evaluation criteria
- identification of effects (costs and benefits)
- quantification of costs and benefits
- valuation, including shadow pricing
- determination of an appropriate time horizon
- discounting to present value
- discussion, where appropriate, of income distribution aspects
- sensitivity analysis
- policy implications

Before the analytical procedures are discussed the technique of 'discounting' and the economic efficiency criteria will be introduced.

Discounting and the economic efficiency criteria

Programmes and projects for rural development or watershed development usually consist of **investment** or **development** activities as well as **production** activities. Although it is not possible to draw a clear boundary between these two, the first one concerns the use of capital resources to create producing assets able to realise benefits over an extended period of time, while the latter involves costs that are rather quickly compensated by benefits. A dam, a tractor or a breeding herd is generally thought of as an investment from which to realise a return over several years, while fertilisers, pesticides and the like are generally thought of as production expenses, which are used up in one production cycle. The difference in the time span during which to expect these benefits, justifies classification as respectively production, and investment activities. How can costs and benefits over the four months period during which vegetables are grown, be compared with the costs and benefits arising from a fruit tree plantation, benefits of which only occur as from the sixth year after planting? The comparison of amounts of different moments in time is complicated by what is called the **time value of money**. Because of this time value 1 dollar now does not have the same value as 1 dollar a few years from now. This is based on the principles of 'the social time preference' (people for various reasons prefer money now in stead of later) and of 'social opportunity cost' (capital can be made productive now). If one is faced with the choice of being given € 1,000 today or after one year, the rational choice is to prefer € 1,000 now, and most people would also accept € 950 now. The amount can be invested now by which a surplus (profit, interest) can be obtained. Costs and benefits occurring now and in the future can not simply be added or subtracted from each other. Therefore the **discounting** technique will be introduced, whereby future costs and benefits can be expressed in terms of values occurring today.

The discounting technique

To explain the technique of discounting first the notion of 'compounding' will be introduced: Suppose you open a savings account with € 1,000 on which the bank pays you an annual interest of 10%. You do not withdraw money from this account for 3 years. The balance on your account will develop as follows:

	now	after 1 year	after 2 years	after 3 years
Balance €	1,000	1,100	1,210	1,331

Three years from now your € 1,000 will be worth € 1,331 at a compound interest rate of 10%. Each year the balance is multiplied by 1.10 (which is the result of (1+ i), where i is the interest rate in decimal notation). After 3 years the multiplication factor is 1.10 x 1.10 x 1.10 = $(1 + 0.10)^3$ or 1.331, which is called the compounding factor. In general terms, the compounding factor for year t at an interest rate of i equals: $(1+i)^t$.

The argument can also be turned around and say that at an interest rate of 10% € 1,331 payable three years from now has a value now of € 1,000. To calculate the **present value** € 1,331 is multiplied by a so called discount factor. In the example the discount factor is 1 / 1.331 = 0.7513 or $1 / (1.10)^3$

The discount factor (DF) for year **t** at an interest rate **i** equals:

$$\frac{1}{(1 + i)^t}$$

The basic formula for the present value (PV):

$$PV = FV_n \frac{1}{(1 + i)^t} \qquad FV_n = \text{Future Value in year n}$$

The present value of € 1,331 equals € 1,331 x DF = 1,331 x $1 / (1.10)^3$ = € 1,331 x 0.7513 = € 1,000.

Table 1. Simple and compound discount factors for 5 years at discount rates of 8% and 10%.

Year	Simple discount rate		Compound discount rate	
	8%	10%	8%	10%
1	0.926	0.909	0.926	0.909
2	0.857	0.826	1.783	1.736
3	0.794	0.751	2.577	2.487
4	0.735	0.683	3.312	3.170
5	0.681	0.621	3.993	3.792

To facilitate the procedure, discount factors are available in tables, see table 1. When every year the same amount is occurring the compound discount rate can be used. It is not easy to choose the right rate of discount (in the above example the discount rate is 10%). The (social) rate of discount is a subjective concept and difficult to determine for any society, but generally guided by the value of interest rate (opportunity cost of capital) prevailing in the country.

The economic efficiency criteria

There are several indicators of project worth or measures of projects' profitability in use, all of which involve discounting and none of which is universally accepted as the most appropriate one.

There are the Net Present Value (NPV), the Benefit Cost Ratio (B/C) and the Internal Rate of Return (IRR). All three measures use the same basic data, namely the discounted values of benefits and costs, but the final information they provide is different.

1. The <u>Net Present Value</u> (NPV) gives the difference between the present value of the stream of benefits and the present value of all costs incurred. A project can only be accepted if this difference (the NPV) is zero or positive and the project with the highest difference (NPV) or surplus should be chosen in case of (mutually exclusive) alternatives, which require at the same time, and in the same area scarce resources (other than capital) and thus cannot both be executed.
2. The <u>Benefit/Cost Ratio</u> (B/C) has much in common with the NPV, but it is a ratio with the present value of all benefits in the numerator and the present value of costs in de denominator. All projects with a B/C-ratio equal or greater than 1 can be considered economically sound, if the discount rate chosen reflects the opportunity cost of capital. The project with the highest B/C ratio is preferred.

3. The <u>Internal Rate of Return</u> (IRR) provides that particular discount rate, that when used in the discounting of benefits and costs, give an equal present value for the benefits and for the costs, or a NPV of zero. That discount rate is called the internal rate of return and represents the average earning power of the money used in the project over the project life. This discount rate can be compared with the opportunity cost of capital in the country, as well as with the borrowing rate for financing the project.

Thus: NPV = B* - C* ≥ 0

B/C ratio = B* / C* ≥ 1

The IRR is the rate at which: B* = C* or NPV = 0

Whereby B* = discounted Benefits and C* = discounted costs.

To illustrate these measures an example will be given, in which both alternatives require the same initial investment (in year 0), the same annual costs, and the same total amount of benefits, but most of these benefits appear later in alternative B than in A. Starting the calculations with the net present value for both alternatives: All values of cost and benefits have to be reduced to their present value (year 0) by multiplying their amount with the respective discount factor. The results are shown in table 3.

Table 2. Example 1: Cost and Benefits of 2 project proposals (in €)

Alternative A				Alternative B		
Investment	Annual costs	Annual benefits	Year	Investment	Annual costs	Annual benefits
11000	-	-	0	11000	-	-
	1300	5000	1		1300	2000
	1300	5000	2		1300	2000
	1300	5000	3		1300	8000
	1300	5000	4		1300	8000

For example the present value of benefits in alternative A with a discount rate of 8% is: 5000x0.926 + 5000x0.857 + 5000x 0.794 + 5000x0.735 = 16,560 or 5000 (0.926 + 0.857 + 0.794 + 0.735) = 5000 x 3.312 which is exactly the compound discount rate (see table 1).

The internal rate of return is also given although it can not be simply calculated with the figures provided. It is calculated in computer through a process of trial and error, trying to approach it. In this example it is rather simple to see that the internal rate of return for the alternative B should be between 8% and 10% since the net present value is positive at a discount rate of 8% and negative at a discount rate of 10%. Similarly it will be found that the net present value for alternative A will be negative at a discount rate of 14%, since the internal rate of return is found to be 13.0%. The NPV for alternative A is indeed € - 219 for a discount rate of 14%.

Table 3. Result of example 1 (in €).

	Alternative A		Alternative B	
Discounted values and Profitability measures	Discount rate 8%	10%	Discount rate 8%	10%
Present value benefits	16.561	15.849	15.797	14.946
Present value costs	4.306	4.121	4.306	4.121
Investment	11.000	11.000	11.000	11.000
1. Net Present Value	1.255	728	491	- 175
2. B/C Ratio	1.08	1.05	1.03	0.99
3. Internal rate of Return	13.0%		9.5%	

In this example all the three measures favour one and the same alternative (A). For both discount rates the NPV and B/C are greater for A than for B, and the IRR for A is greater than for B.

Identification of costs and benefits

1. The 'with and without' - concept

Any effect of a programme should be identified and measured on the basis of the difference in a given situation with and without the programme of project. The <u>without</u> case should <u>not</u> be considered in terms of the situation <u>before</u> the project, since it is very likely that changes will also take place in the absence of the project.

This is very clear in a soil conservation project, where it is anticipated that in the absence of proper soil protection measures soil losses will occur gradually to such an extent that the level of production will decline. (On the spot as well as downstream). The correct '<u>net</u>' benefit measure in this case would include the difference between the declining production without the project and the production level that can be achieved with the protection measures of the project.

In case a programme intends to accelerate the utilisation of fertilisers, it can be assumed that even without the programme the use of fertilisers will increase, although at a slower rate. With regards to the costs, care has to be taken to identify properly the best actual opportunity foregone i.e. the best alternative use made of the inputs in the absence of the programme.

2. Identification of costs and benefits of programme-components and comprehensive programmes

A programme usually consists of interrelated components. Some of these can be defined separately in the sense that most of their costs and benefits are independent from the rest of the programme and the components can be added to (eliminated from) the project without affecting its technical feasibility. They should be identified separately and the inputs allocated to each of them, since each separate project component should have benefits at least equal to costs in order for the project as a whole to be considered an economically efficient use of resources.

A distinction can be made between direct or indirect effects (costs or benefits):

a. Direct costs (inputs). The main source of information on direct inputs will become available from technical studies (like crop input/output studies and soil conservation specification tables) and the quantities of various inputs will be entered for the separable components in intermediate and final physical flow tables by categories and period.

The following types of direct input categories can be distinguished:

- Manpower	Unskilled, skilled staff etc.
- Land	Land use and land value (slope and soil depth)
- Equipment	Source: local or imported
- Raw material	Source: from government utilities, own production, local available or imported
- Structures and civil works	Purchase or rented, (in case of own construction costs to be included in other categories (manpower, material, etc.)

b. Direct benefits (outputs). Direct outputs can also be derived from technical studies, as well as from market studies. They also appear first as quantities in the physical flow tables.

The following types of direct benefits can be identified:

- Increased value of agricultural production
    - Greater physical production
    - Quality improvement
- Better location and timing of agricultural production (storage, transportation)
- Changes in form (grading and processing of production)

- Cost savings
  - Reduced transportation cost
  - Reduced cost of dredging of reservoir through watershed protection
- Losses avoided
  - Soil erosion prevented
  - Storage against post harvest losses

c. Indirect costs and benefits Indirect effects or 'externalities' are defined as the positive or negative impacts of a programme, not reflected in the financial accounts of the programme or the respective entities. Indirect effects can be tangible or intangible and positive or negative.

Some positive indirect effects are:

1. The 'stemming from' and 'included by' effects: An increase in production due to the programme will involve increased activities by traders, transporters, processing firms, etc. and on the other hand increase the turnover of organisations providing inputs.
2. The 'economics of scale' effects: The increase in production through the programme can reduce the excess capacity of processing facilities, and can save costs in storage and transportation.
3. The 'dynamic' effects: Persons trained through the programme will be more productive and activities undertaken by the programme and proven viable may subsequently be undertaken outside the project area (training and demonstrations).

Intangible effects can be manifold: examples of the intangible costs associated with the construction of dams and reservoirs may include the damage to natural beauty and scenic values, to the ecology of wildlife, the relocation of people, etc. Intangible benefits on the other hand may be the greater security against loss of life, new recreational opportunities etc.

There are different possibilities to cater for important intangible effects. One approach is to describe, these effects in physical terms and present them next to the ones which can be measured in monetary terms. Another more sophisticated approach is to try to translate intangible values into tangible values.

For the calculation of costs and benefits for soil and water conservation it is important to realise that:

A benefit foregone is a cost.

Cost avoided is a benefit.

For instance when land is taken out of production, the production foregone is a cost. When by protection of soil loss, dredging of the reservoir is hardly needed, the cost of avoided dredging is a benefit. More soil erosion leads to a reduced yield, so more soil erosion leads to a benefit foregone.

Double counting has to be avoided. When measures are taken to avoid floods, the benefits of reduced floods can be estimated from examining flood damages avoided or the change in land value. They should not both be counted since reduced flood damage will probably be the cause of the increased property values. Therefore, changes in land value will incorporate reductions in flood damage.

In determining the costs in cost-benefit analysis **depreciation is not included**. The resulting cash flow is therefore simultaneously the return **of** capital (which would include depreciation) and the return **to** capital. Depreciation is automatically taken care of, thus avoiding the often difficult choice about what depreciation schedule to follow.

It is reasonable to assume that the general price level will increase: **inflation**. In project analysis the effect of inflation are eliminated by using constant prices, and as a necessary consequence thereof to use a net discount factor for discounting. The underlying assumption is that inflation will affect all cost and benefits similarly, so that the price relations do not change. Adjustment must be made in case a change in relative prices is expected. Changes of this nature reflect real shifts in the value of inputs and outputs in economy (Putte & Paats, 1991).

The economic and financial analysis

It is not only the Central Government with its (national) objectives that has an interest in the project. Other participants such as government corporations, private firms, merchants and farmers are also involved and will take decisions based on their own objectives. Private versus national objectives influence the appreciation of costs and benefits. <u>Financial</u> analysis considers costs and benefits from the standpoint of the individual (enterprise) concerned and reflects private-economic interest. The <u>economic</u> analysis reflects national-economic considerations and deals with costs and benefits from the point of view of society as a whole. For example a government decides to subsidise fertiliser for $ 10, resulting in a price of $ 40 per bag to the farmer. The financial analysis for the farmers will be based on a price of $ 40 per bag. For the economic analysis, however, the full price of $ 50 must be used. Table 4 gives an overview of the differences between financial and economic analysis.

The analytical tools for both types of analysis are identical. In practice, the time streams of financial costs and benefits are a good starting point for identifying the economic costs and benefits of a project. The steps in a financial analysis will therefore be described first.

Table 4. Differences between financial and economic analysis (Source: James, 1994).

Characteristics	Financial analysis	Economic analysis
Purpose	Indication of incentive to adopt	Determine whether investment is justified in economic efficiency terms
Accounting stance	Developer, Actors involved	Society, Nation as a whole
Discount rate	Marginal cost of borrowing money	Social discount rate
Transfer payments	Relevant to analysis (included)	Not relevant to analysis (not included)
Prices	Market prices	Shadow prices may be required
Costs	Price of all inputs	Opportunity costs of all inputs
Benefits	Revenues	Real benefits to economy as a whole

Financial analysis

Just as for an enterprise, the profits (or losses) of a programme or project equal the difference between its earnings and its costs, taken over a certain period of time, and these can be split up according to each specific entity participating in the project. In the financial analysis the costs and earnings are expressed in their actual money value, at **market prices**.

Overall financial analysis

The following four major steps are involved in the overall financial analysis:

1. Inputs actually purchased or rented are identified in terms of when they are needed (in quantities). Similarly outputs, traded on the market are identified in terms of when they are sold. This information results in a **physical flow** table.
2. Market prices for the input and outputs are estimated for the time at which inputs will be bought and outputs sold. This information is entered into **unit value** tables.

3. The information from the previous steps is combined into a **cash flow** table, which shows the value of total inputs and outputs at the times that such values (outflows and inflows of money) accrue to the entity from which point of view the analysis is being undertaken.

   To complete the cash flow table, certain financial transactions which involve transfers of control over resources (but no use of real resources) are added to the table. Such items as taxes and loan repayments (outflow) and subsidies and loan proceeds (inflows).

   Finally, the inflows and outflows of funds are totalled by years in which they occur to arrive at a net cash inflow (outflow) line. See table 5 in which all output (of wood) and inputs (labour and other) are expressed in market prices.

4. The last step involves using these net value figures by years to derive some **measure of economic commercial (financial) profitability**.

Table 5. Illustration of financial cash flow table of eucalyptus-afforestation component (in € 1000)

YEARS										
OUTPUTS:	-1	0	1	2	3	4	5	6/7	8/9/10	11/12/13
Sawlogs	-	-	-		40	40	300	600	1500	900
Small poles	-	-	-	-	130	130	300	400	300	50
Pulpwood	-	-	-	-	60	60	150	200	200	100
TOTAL OUTPUT					230	230	750	1200	2000	1050
INPUTS:										
Land clearing/roads										
Labour	20	20	20	20	20	20				
Other	200	200	200	200	200	200				
Planting/management										
Labour	10	80	100	120	140	150	160	90	60	30
Other	20	100	150	200	250	250	250	160	130	90
TOTAL INPUTS	250	400	470	540	610	620	410	250	190	90
Net-inflow/ Outflow (-)	-250	-400	-470	-540	-380	-390	+340	+950	+1810	+960

(National) economic analysis

In what respect does a measure of financial profitability differs from that of national economic profitability? Are commercial profits a bad guide to social gains? That depends among others on the extent the market prices reflect the true values to the country as a whole, and are not distorted by subsidies, taxes, protective trade policies, maximum wages legislation etc. These **market price distortions** are often deliberately created and usually **reflect** the government **objectives** and policies but this makes it necessary to change the scheme, in such a way as to obtain the highest economic profitability for the (national) society as a whole.

Considering the same four steps as for overall financial analysis, the following changes are required:

1. In developing the physical flow table, also **indirect effects** should be included, i.e. effects which are not included into in the financial analysis since they are not directly traded in the market. Examples are the excessive smoke and pollution a particular industrial project might produce, a favourable effect of a labour intensive project on unemployment, or the downstream hydrological effects of an afforestation programme.
2. For the unit value tables, the **prices have to be adjusted to represent the real economic value to the society**. The resulting values are usually called **shadow prices**. In a perfect market the shadow price for any resource would be its market price. But in reality, market imperfection, such as tariffs, quotas and monopolies and transfer payments, such as taxes and subsidies, create distortions in demand and supply and market prices of inputs and outputs may then not reflect the true economic value. Theoretically, all shadow prices should be derived from a comprehensive mathematical model of the economy, but in practice shadow pricing is carried out selectively for major inputs and outputs. Examples are given of how to arrive at shadow prices for a few important items:

   a. <u>Foreign exchange</u>: Add average direct and indirect export subsidies to official buying rate to form effective export rate. Add average import tariffs to official selling rate to form the effective import rate. A special case for which corrections must be made is caused by the <u>overvaluation of local currencies</u>. Adjustment of the exchange rate is quite complex and the subject of an extensive body of literature. If no other information is available an exchange rate somewhere between the official rate and the black-market rate will have to be selected (Putte & Paats, 1991).

   b. <u>Unskilled farm labour</u> (unemployed or under-employed): The opportunity cost of farm labour (on annual basis) can be estimated by multiplying the wage rate when labour is scarce by the number of days in a year when it can be considered that labour is reasonably fully employed.

c. Output of agricultural products: For those agricultural commodities which are internationally traded and which imports can be an alternative to domestic production **world market prices** can be a good estimate of the opportunity costs.

d. Farm inputs: If the programme can have an important impact on the further local production of certain farm inputs (seeds, planting materials, equipment) for which the market price might be distorted, **local production costs** could be the best estimate to take as shadow price.

3. 'With indirect effects' included in the 'physical flow tables' and shadow prices applied where appropriate in the unit value tables, the economic value flow table can be constructed.

   Transfer payments are not treated separately, but included as part of economic costs or benefits where appropriate. Taxes and loan costs are not to be subtracted from benefits (or treated as costs) and subsidies and loan receipts are not to be added to benefits (or netted out of costs).

4. With values given in economic value flow table, calculations can be made regarding the economic profitability or efficiency.

Valuation techniques for conservation projects

Projects and programs are nearly always evaluated on the basis of costs and benefits. The problem then arises what are the costs and benefits. When quantities and prices are known there is no problem, costs and benefits can be weighted. However, very often the costs and benefits are very hard to value, especially for environmental projects. Depending on the type of environmental problem and the availability of information on quantities, qualities, prices, etc, various different approaches or techniques can be followed to value the benefits/costs of changes with regard to the environment (e.g. conservation).

The valuation approaches can be divided into three different categories:

1. Conventional market prices
2. Implicit market prices (surrogate or hedonic prices), market values of substitutes
3. Artificial market prices (hypothetical or contingent valuation), values derived from surveys

Table 7 lists some techniques and Box 1 gives an example of estimating value of fuelwood in Nepal.

Table 7. Selected valuation techniques

Making use of:	Costs (or benefits)	Example[1)]
1. Conventional market prices	Changes in value of output	(No further) declining crop yields
	Loss of earnings	
	Preventive expenditures	(Preventing) floods
	Replacement cost	(Avoiding) desilting structures
		(Avoiding) replacement damaged turbines
		(Avoiding) replacement nutrients (fertiliser use)
2. Surrogate or implicit market prices	Property/land value approach	Changing property value due to (reduction of erosion or flooding)
	Travel cost approach	(No) loss of recreational value
3. Hypothetical or contingent valuation	Survey approach: direct questioning willingness to pay	Estimating willingness to accept compenstation for loss (pay for) use reservoir fishery
	Tradeoff games	Estimate value of decreased soil erosion
	Bidding games	Changes of herds, with grazing fee

1) For valuation of costs or benefits (in brackets). Source: Gregersen et al., 1987.

Conventional market prices

When costs and benefits of certain goods or services can be assessed on the basis of market prices and those market prices do reflect adequately the willingness to pay, the first group of methods can be applied. Market prices are generally easy to observe and readily accepted by decision-makers.

One of the most used techniques is the **change in productivity** approach: a with and without analysis will allow to understand the difference between the productivity with and without the project with market prices used. A well-known method for estimating the long term benefits of soil conservation projects or activities (e.g. terracing with annual cropping), compares the production or productivity with conservation measures with the declining production without such measures, over a period as long as the physical or economical lifetime of measures concerned. This method is based on the premises that soil depth reflects past erosion, and that there is a certain relationship between crop yields and soil depth. In areas with homogeneous or shallow soils, it concerns the total soil depth, while in other zones it will concern the depth of the top soil layers. It is then sufficient to know the present soil depth, the annual rate of erosion and average yields for a few selected soil depths to derive a time series of crop yields over the period considered for the economic analysis (often 20 years). The most important levels of soil depth are that from which root development is impaired and crop yields start to decline (Dm), and that at which no real production can be expected anymore (Dz). For such an assessment a series of crop studies has to be undertaken to estimate the relationship between soil depth and crop yields under otherwise homogeneous agro-ecological conditions.

Another method for calculating the benefits is the market value of **replacement costs**. For example the value of erosion control is valued in terms of the savings of fertilisers that were formerly required to maintain production at a certain level. If erosion is controlled and fewer nutrients and less top soil are washed away, less fertiliser would be needed to maintain fertility. The value of this fertiliser savings is a measure of the benefit of reducing erosion.

When the **cost effectiveness** method is used, one calculates for instance the costs of different ways of reaching the same level of erosion. If one way is clearly cheaper than the others and the benefits are the same, then this information provides information for decision making. When this method is elaborated it is also known as Cost Effectiveness Analysis (CEA): one can either look for the alternative that can reach the objectives at minimum cost, or the alternative that can make the maximum contribution to the objectives at fixed costs. The method avoids the painstaking effort required to estimate the various tangible and less tangible benefits. The method is mainly used as a (poor) substitute to Cost Benefit Analysis, when the benefits are of similar magnitude and when it is too difficult to quantify and value the major categories of benefits.

The value of fuelwood in Nepal

Products for which a market price is often not available, since these are often both 'collected' as well as consumed or utilised by the rural households, are fuelwood and manure.

Fleming provides an interesting example from Nepal, whereby the valuation of fuelwood is approached in three different ways.

1. Direct approach (market value). A small amount of fuelwood is sold in local markets at Rs 13 for a 37.3 kg bundle. Assuming an average density of wood of 500 kg per m^3, this (sold) fuelwood would be worth Rs 174 per m^3.

2. Indirect approach (substitute method). Fuelwood can also be valued in an indirect way in terms of the resources it would replace (e.g., the productive value of the cattle dung that is burned when wood is not available). The following is assumed:

a) 1 m^3 of wood equals 0.6 tons of dried cattle dung, which equals 2.4 tons of fresh manure;

b) an average family (5.5 members, 3 livestock units) uses 6 tons of fresh manure per year on a cultivated area of 0.75 ha;

c) the expected increase in maize yields is assumed to be 15 %; giving an opportunity cost of Rs 40/ton for fresh manure.

On the basis of these assumptions, the value of fuelwood is Rs 96 per m^3 (Rs 40 x 2.4).

3. Indirect approach (opportunity-cost approach). This approach is based on the value of the time spent by families collecting fuelwood in the forest. It is assumed that 30 kg of fuelwood are collected per day, and that an average of 132 workdays effort are spent each year by a family in fuelwood collection, and that the 30 kg of fuelwood are equivalent to 20 kg of dry wood, with a volume of 0.04 m^3. Therefore, each family gathers 5.28 m^3 of fuelwood per year. At an average (no distinction between family members) opportunity cost of Rs 5 per day, the estimated value is: Rs 5 x 132/5.28 = Rs 125/m^3.

These three approaches give different estimates of the value of fuelwood, ranging from Rs 96 -Rp 174 per m^3. The difference is the resultant of the various assumptions made, but in the case of the fuelwood sold might also relate to quality. In order to be conservative the lowest value was chosen in that analysis.

Box 1. Valuation Techniques *Hufschmidt et al, 1983.*

Surrogate market prices

In case (environmental) costs and benefits can not directly be estimated through market prices, one could look for clear substitutes which do have market prices (surrogate or hedonic prices). There is for example no market for soil eroded from upland fields, but one could approach the value by comparing the market price of eroded upland fields with those unaffected by erosion. Additional data might have to be collected, for example on the changes in the sale prices of properties (e.g. houses, farm land) after and related to the implementation of certain projects (e.g. road construction, establishment airport).

Sometimes market prices are felt to be distorted, then surrogate market approaches can be used to develop shadow prices. For example, a common shadow pricing problem is that of labour in a development project area with high unemployment. If the project generates new employment and if there is a government mandated minimum wage, then this minimum wage is not likely to adequately reflect opportunity cost for the use of the previously unemployed labour. The minimum wage will be higher than the true opportunity cost of employing additional workers. This opportunity cost will be taken as the shadow price for labour. Since the shadow price is lower than the government set minimum wage, the economic analysis will favour alternatives that use relatively more labour than capital.

Hypothetical or contingent valuation

When no direct market prices are available and no substitutes can be identified for which market prices exist, it may be possible to obtain some value information by means of surveys, or through expert judgement. In the case of trade off games respondents are offered various combination of states of the environment and money. The aim of the exercise is to discover people's rate of substitution between environmental quality and cash. An example of bidding games is when a sample of households is asked, to what extent they would reduce their sheep and goat herd in case of a certain grazing fee per animal, or what (fictitious) fee they would be willing to pay for visiting a nature reserve. In case of subsistence farmers in developing countries the donation of labour or bags of maize, etc may be more appropriate yardsticks in such questionnaires than monetary values. The results of such type of analysis have to be interpreted carefully.

Specific aspects of cost-benefit analysis for soil and water conservation

1. The time frame and length of a programme

For an (investment and production) programme usually three different stages can be distinguished:

a. Construction or implementation
b. Adoption
c. Full production (normal operation).

In practice these three periods overlap, particularly when the programme comprises many components and several sectors (areas). While the construction work for one component for example bench terracing, in one area may have been completed and the level of full production already attained, the construction and implementation of another component e.g. irrigation may still be under way.

These stages and their overlapping complicate the determination of the length of the project period. For the programme as a whole, a general recommendation is to consider a time period that is long enough to include all the major effects of the project that can be foreseen, and when the last components and sectors have for some time reached the stage of full production. However uncertainties about the future may also limit the period for which analysis is meaningful. As a very roughly rule of thumb it can be said that project periods should not exceed 25-30 years. With a high discount rate any return to an investment 25 or 30 years from now will probably make little difference in the final analysis.

2. Discounting

When the technique of discounting is used the costs and benefits in early years of project weigh heavier than those in later years. For example with a discount rate of 10% the costs or benefits in the period from the 25th to the 50th year after the start of the project, are weighed less than 10% of the costs or benefits in the first 25 years. For degradation and environmental problems this creates a problem. Consider a development that yields immediate and near-term benefits but has fairly catastrophic environmental consequences for future generations. So long as the weight attached to the future gets less and less the further one goes into the future the less important catastrophic losses will be. In other words, discounting contains an in-built bias against future generations.

For environmental projects a rather low discount rate would be best, because the benefits in the future will be more worth today when the discount factor is low. However when a low discount rate is chosen, more projects will be profitable and more projects will be carried out. This will lead to more use of resources, which will be depleted earlier. For all these reasons discounting does appear to be inconsistent with the ideas of conservation and sustainability.

Cooper (1981) proposed to determine NPV's with multiple base years, for example also using year 30 as base year, in order to show the results of a project form the point of view of the next generation.

Pearce and Turner (1990) propose to apply a 'rate of demand growth' correction factor for preservation benefits (producing an effect similar to lowering of the discount rate) and a 'set of compensating investments', to maintain the flow of services from a given stock of environmental goods. The concept of 'option value', can be considered in addition to the normal 'user value'. Option value is that what people are willing to pay to preserve an environmental service even if they do not actually use that service. But this concept is more useful in dealing with the loss of unique parks or other recreational sites, than in case of losing agricultural land. And since park owners find it hard to capture such 'option value', the concept has not been applied in financial CBA (Conrad & Clarke, 1987).

3. Discount rate

In CBA all streams of future costs and benefits are discounted to their present value. For financial analysis the discount rate is usually equal to the marginal cost of money to the enterprise for which the analysis is done, frequently the rate at which the enterprise can borrow money.

For economic analysis the situation is somewhat more complex. There alternatives are possible:

1. The opportunity cost of capital, or the return on the marginal investments that uses up the available capital.
2. The borrowing rate that the country must pay to finance the project.
3. Social time preference rate or the discount attached to future returns by society. This is generally lower than the individual discount rate, as society has normally a longer time preference.

In most developing countries the proper discount rate is often assumed to be between 8 and 12% (higher than in developed countries).

4. Labour costs

A lot of soil conservation projects require a lot of labour. The required additional labour of the farmer can only be justified if its cost is rewarded by higher returns. This is however often neglected which at the end can result in not-acceptance of the farmers because of the high labour requirement, which was assumed to be abundantly available. It is, therefore, essential to value labour accurately. Returns to labour should also be estimated in the cost-benefit analysis in order to make decisions on the right criteria (Stocking and Abel, 1989).

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The Common Agricultural Policy: A Brief Introduction

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The Common Agricultural Policy (CAP) for the European Union was established in 1963 and has provided the basis for Europe's food and agricultural programs. This short introduction presents a brief history of the CAP, its establishment and the different reforms over time as well as some overview of the current context in European agriculture today. It also addresses the CAP review scheduled to take place in 2008.

Establishment of the CAP

The CAP was initiated after World War II as part of the Treaty of Rome that was signed in 1958. Following post-war shortages, Europe began to explore ways to become self-sufficient in food and agricultural production at the regional level. The Treaty of Rome set the stage for the CAP by establishing guaranteed markets as well as a fair price for agricultural producers.

The CAP went into effect in 1963 with four basic principles:

- **A unified market for the free movement of agricultural products in the European Union covered by community preference.**
- **Financial solidarity:** All costs of the CAP were to be financed out of a communal treasury, FEOGA (European Fund for Orientation and Agriculture Guarantee), supported by import tariffs and contributions from European countries.
- **Community preference:** European products were to be given preference over imported products.
- **Parity and productivity:** Farmers' incomes were to be equal to incomes in the other sectors, with reasonable prices in order to permit food access to the consumer.

Common Market Organizations (CMOs) were also introduced in the original CAP and still exist today. Within CMOs, each group of food and agricultural products is organized by harmonized rules. CMOs set minimum prices for products at the EU-wide level. Currently, there are 21 Common Market Organizations.

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During the 1960s and 1970s, the CAP led to increased agricultural production in Europe and was generally considered a positive vision for growth in the post-war region. However, by the 1980s negative environmental effects of increased production (e.g. water pollution and soil impoverishment) began to surface. Structural overproduction became entrenched in European agriculture, which routinely produced more than those in the community could consume. As part of this trend, storage for surpluses in products such as milk, cereals and meat became increasingly expensive, and the European Community began exporting its excess products at below world prices (known as dumping).[1] In the 1980s, the EU began its systematic reform to deal with overproduction, negative impacts on the environment and dumping.

Cap reforms over time

1. Introduction of milk quotas in 1984

The first CAP reform was the introduction of the milk quota in 1984. The milk quota was put into place as a means to control dairy production and overall EU expenditures. While the milk quota was reasonably effective in limiting production in the EU, the limit was set in excess of the domestic consumption of dairy products in the EU. Hence about 10 percent of the production still had to be exported and since the minimum prices in the EU remained above world market prices, this was only possible with export subsidies. Dumping was reduced, but not eliminated. At the same time, the structural overproduction exerted a downward pressure on domestic milk prices, which were usually at the level of the minimum price set in the EU. Since this minimum price was hardly adjusted upwards, small dairy farmers continued to go out of business, albeit at a somewhat slower rate than they would have without the quota.

2. Mac Sharry reform in 1992

The Mac Sharry reform marked the beginning of direct payments in order to compensate for the decrease of the price support. The Mac Sharry reform enacted price cuts for agricultural products (meat and cereals) as a means to ensure competitive domestic and international markets. Farmers were partly compensated for the lower prices through direct payments, based on the area on which they plant certain crops. In order to be eligible for these payments farmers also had to set-aside a certain amount of their land and limit the number of animals per hectare. It also introduced new subsidies to farmers for good environmental practices. There was a significant increase of direct payments that resulted from this reform.

3. The Agenda “2000”

Signed in 1999 in Berlin, the Agenda 2000 created the second pillar within the CAP to take into account the “multi-functionality” of farming activities. Three main measures were proposed (among more than 15): agro-environment schemes, support to the least favored areas, and investment assistance to enhance productivity and competitiveness. The first pillar from the earlier CAP only addressed support for agricultural products. The modulation principle in the Agenda "2000" introduced measures to allow for funds to be transferred between the first pillar to the second based on this "multi-functionality" approach. In 2000, the EU expanded its basis for direct subsidies programs to address long-term goals for development.

4. The 2003 reform and the current CAP

In 2003, further reforms were introduced, which are in the process of being implemented today. These reforms coincided with the entry of 10 new countries from Eastern and Southern Europe into the EU - followed by two other countries which entered the EU at the beginning of 2007.[2]

The most important step was to decouple direct payments to farmers. Farmers today are allotted payment entitlements based on historical reference payments during the period of 2000-2002, largely independent of what they currently produce. These payments are brought together under the name of single farm payments (SFP). Each country can choose if the payment will be established at the farm level or at the regional level. Farmers receiving the SFP have the flexibility to produce any commodity on their land except fruit, vegetables and table potatoes. In addition, they are obligated to keep their land in good agricultural and environmental condition (cross-compliance). Countries that wish to can keep some subsidies linked with limited production. These subsidies are called "partial decoupling payments." For instance, in Great Britain all payments are decoupled, although in France some payments are still linked with limited production (e.g. payments for sheep are decoupled at 50 percent. This means that the farmer receives the total of the payment only if he still farms sheep. If he stops his breeding, he receives just 50 percent of the payments).

In 2003, the milk quota increased, prices continued to fall, and further subsidies were integrated into the SFP. The full granting of the SFP as part of the 2003 reform is linked to the compliance of a certain number of environmental, food safety, animal and plant health standards. Direct payments as formerly defined in the first pillar decreased by 3 percent in 2005 and by 4 percent in 2006 (modulation). It is expected direct payment cuts will reach 5 percent between 2007 and 2013 (this is called modulation of subsidies). However, the money formerly allotted to direct payments is now earmarked for the 2nd pillar of the CAP to support the environment, animal welfare, food quality and safety, and to invest in agricultural production.

Also in 2003, the EU initiated a directive to expand production of biofuel feedstocks to support its overall goal of decreasing greenhouse emissions. It set a target for 5.75 percent by 2010 and 8 percent by 2015. In real terms, however, Europe lacks arable land available for energy crops. It is already importing biofuels. This has become contentious at both the regional and global level because of the concern that intensive biofuel production will not support sustainable development goals and the concern that European energy goals could potentially do more harm than good.

Review of the CAP in 2008 and beyond

In 2008, a review of the CAP will begin. Among others the following themes and issues will be discussed and/or will shape the future CAP:

Common Market Organizations: Currently, there are 21 Common Market Organizations and the EU Agriculture Commissioner, Marian Fisher Boel, has proposed to collapse them into one single Common Market Organization as a means to simplify the CAP and to increase EU competitiveness in the world market.

The Common Market Organizations govern production and trade of agricultural products from each member states of the EU. They aim to reach the CAP objectives and notably stabilize the market, increase agricultural productivity and guarantee a stable income for farmers. The CMOs cover about 90 percent of the agricultural production in Europe. The 21 CMOs are: cereals, pork, poultry and eggs, vegetables and fruits, banana, wine, dairy products, beef meat, rice, olive oil and olives, sugar, flower-growing, dry forages, fruits and vegetables added value, tobacco, flax and hemp, hop, seeds, sheep and goat meet. For practical purposes, the CMOs set the price of agricultural products for each European market.[3] (They allocate subsidies to producers in the sector, establish the mechanisms that regulate the production (quotas, set aside, national guaranteed quantity) and set the terms for exports and imports with developing countries.

A single CMO would further deregulate European agriculture. It is difficult to see how one common market organization could address the specificities that are linked to different products.

The EU-Budget: The budget remains a bone of contention among members of the EU, even though the CAP's budget is guaranteed until 2013. In fact, it could potentially be reviewed as early as 2008 or 2009 because some states have argued that agriculture consumes too much of the budget (essentially UK and the Nordic countries). The CAP budget is currently comprised of 54.7 billion Euros (71.7 billion dollars) per year, of which 40 billion are spent for the first pillar, i.e. mainly direct payments. However, the share of the CAP in the EU budget is regularly decreasing: today it represents 43 percent of the overall budget while in 1984 it represented 70 percent of the overall budget. This represents a marked shift over the last 20 years.

Even as it has decreased greatly, the agriculture component of the EU budget is still notably large. Part of the reason for this is that most agriculture policies and hence government spending is decided at the EU level.

Interestingly, a new debate around the need for a common budget to support a European agriculture policy has emerged. Some countries propose to abolish the financial solidarity principle and bring the CAP to an earlier iteration that had been financed by countries individually rather than collectively. This would imply that wealthier countries such as Germany, France, Austria, Netherlands and

Sweden could more easily support their agriculture. Yet, the new member states have less national wealth and would lose with this scenario. The new member states need investment to modernize their agriculture programs and to ensure that agricultural production is environmentally and socially sustainable. Eastern states would also seek to receive a larger part of the budget. Resolving this imbalance within the CAP budget will continue to be a difficult negotiation within the ever-changing EU.

Milk quotas: Milk is one of the few remaining commodities in which production limitations exist to ensure a higher market price. Agricultural Commissioner, Marian Fisher Boel, stated in her February 2007 speech that milk quotas are "out of place in the reformed CAP."[4] Milk quotas do not encourage competitiveness, which is the main focus of the Lisbon strategy. "Quotas hamper competitive producers by preventing them from expanding." In light of the impacts of the reforms already in place, one can expect that dairy will be the subject of a contentious debate in the 2008 mid-term review.

Allocation and transparency of CAP payments: For 2008, Agricultural Commissioner Boel has made decoupled payments for all countries and all producers a priority for the European agenda. The implementation of this decision will be reviewed. Another key issue in relation to CAP payments is the so-called transparency initiative. Based on the critique and existing information to whom payments go in a few member states, transparency has become an important issue. Linked to this issue, the debate on how to improve the cross compliance and payment limits will certainly come up in the 2008 debates.

Biofuels: Recently the EU has established biofuel targets. The overall EU goal is to reduce climate change. As such, it is committed to decreasing CO_2 emissions by 20 percent over the next 13 years. The Commission proposed a fixed target to ensure that by 2020, renewable energy will represent 20 percent of its total energy consumed, including a 10 percent minimum in biofuels.

The demand for biofuels has triggered a price increase for commodities in the EU- at least in the short-term. In response, some farmers have shifted to biofuels production to improve their income. The debate around biofuels and climate change will certainly influence the direction of the CAP.

5. Some Positions for the 2008 CAP review

Below are the positions on the general direction of the CAP and agricultural budget by some interest groups:

The food-industry seeks further liberalization in support of cheaper raw materials and new food markets. The Committee of Industrial Users of Sugar supports more competitive agriculture and low sugar prices.

CIAA (food and drink industry confederation) supports simplification of the CAP but does not agree with a single common market organization that has the potential to worsen, not lessen European bureaucracy in agricultural products.

The public health community has started to work for on CAP review in order to ensure that health is taken into account. There is a concern that the CAP has a link to a growing number of major diseases and disorders (obesity, high blood pressure, type II diabetes etc.) that are food related. The European public health alliance explains, “The CAP doesn’t support healthy crops, such as the fruit and vegetable sector. There is a shortage of fruit and vegetables in the market, which make them expensive and unaffordable to low income families.”

“Small farmers” have been critical of the 2003 reform because payments have been based on historical production. This has meant that the most productive farmers, which are the large-scale corporations, have received the lion’s share of these payments. However, the farming lobby is better organized and more effective than the loose coalition of consumer groups, Greens and development NGOs that seek to challenge the current reforms in the CAP.

The CPE (European Peasant Coordination) does not support a decrease in the EU agriculture budget, but does support better management of the funds. This organization supports the solidarity principle. The CPE and COAG (coordination of Ganaderas farmers’ organisations) support a reduction in the bureaucracy of the current Common Market Organisation (CMO), but express their concern that shifting to a single CMO will be used by the European Commission to suppress market regulation.

Similarly, in a common declaration “Re-thinking the CAP,” World Wildlife Fund, Oxfam, Bird Life, Eurogroup, Friends of the Earth, International Federation of Organic Agriculture Movements (IFOAM) EU Group and European Environmental Bureau (EEB) have stated that the debate must not just centre on how much is spent on the CAP but also on how funds are allocated. They have also taken a position against the total decoupling of payments.[5]

The European Dairy Association generally supports the liberalization of dairy production provided there is a phase-out process that would block any immediate reduction of import tariffs that could destabilize the EU milk market.

CEFIC (Council of the European Chemical Industry) has stated that industrial biofuels are potentially problematic because they are energy inefficient and could compete with production for food.

6. Structure of decision-making within the CAP

The European Commission, composed of commissioners designated by the member states, submits proposals to the European Council. The current Agricultural Commissioner is Mariann Fischer Boel (Danish).

The Agricultural Commissioner has the task to develop-based on consultations with the Member States and stakeholders – a proposal for a new CAP. This proposal is finally reviewed and decided upon by the European Council of Agriculture Ministers. The European parliament has only a consultative role.

7. CAP reform - a long-term perspective for sustainable agriculture

(Some more details on 2003 Reform http://ec.europa.eu/agriculture/capreform/index_en.htm)

On 26 June 2003, EU farm ministers adopted a fundamental reform of the Common Agricultural Policy (CAP). The reform will completely change the way the EU supports its farm sector. The new CAP will be geared towards consumers and taxpayers, while giving EU farmers the freedom to produce what the market wants. In future, the vast majority of subsidies will be paid independently from the volume of production. To avoid abandonment of production, Member States may choose to maintain a limited link between subsidy and production under well defined conditions and within clear limits. These new "single farm payments" will be linked to the respect of environmental, food safety and animal welfare standards. Severing the link between subsidies and production will make EU farmers more competitive and market orientated, while providing the necessary income stability. More money will be available to farmers for environmental, quality or animal welfare programmes by reducing direct payments for bigger farms. The Council further decided to revise the milk, rice, cereals, durum wheat, dried fodder and nut sectors. In order to respect the tight budgetary ceiling for the EU-25 until 2013, ministers agreed to introduce a financial discipline mechanism. This reform will also strengthen the EU's negotiating hand in the ongoing WTO trade talks. The different elements of the reform will enter into force in 2004 and 2005. The single farm payment will enter into force in 2005. If a Member State needs a transitional period due to its specific agricultural conditions, it may apply the single farm payment from 2007 at the latest.

8. Key elements of the reformed CAP

- A single farm payment for EU farmers, independent from production; limited coupled elements may be maintained to avoid abandonment of production,
- this payment will be linked to the respect of environmental, food safety, animal and plant health and animal welfare standards, as well as the requirement to keep all farmland in good agricultural and environmental condition ("cross-compliance"),
- a strengthened rural development policy with more EU money, new measures to promote the environment, quality and animal welfare and to help farmers to meet EU production standards starting in 2005,
- a reduction in direct payments ("modulation") for bigger farms to finance the new rural development policy,
- a mechanism for financial discipline to ensure that the farm budget fixed until 2013 is not overshot,
- revisions to the market policy of the CAP:
  - asymmetric price cuts in the milk sector: The intervention price for butter will be reduced by 25% over four years, which is an

additional price cut of 10% compared to Agenda 2000, for skimmed milk powder a 15% reduction over three years, as agreed in Agenda 2000, is retained,

- reduction of the monthly increments in the cereals sector by half, the current intervention price will be maintained,
- reforms in the rice, durum wheat, nuts, starch potatoes and dried fodder sectors.

The legal texts were formally adopted at the Agriculture Council of September 2003.

9. Implementation of the reform

With regard to the implementation of the reform, the Commission has chosen to do this by way of three Commission Regulations.

Regulation 1 covers the provisions concerning cross-compliance, controls and modulation. The provisions with regard to cross compliance are one of the new key elements in the CAP reform, which make the future Single Farm Payment dependant on the farmers respecting public health, animal health, environmental and animal welfare, EU norms and good agricultural practice.

Regulation 2 embodies the key element in the reform of introducing a Single Farm Payment, where the payment will no longer be linked to production (decoupling), allowing the farmers to have their incomes ensured and steering their production towards the needs of the markets and the demands of the consumers. Payments will, however, only be paid in full if the above cross-compliance provisions are respected. At the same time decoupled payments will mean that a major share of our support to agriculture is moved from the trade distorting classification under WTO rules (Amber Box) towards the minimal or non-trade distorting category (Green Box).

Regulation 3 covers those areas of support, which in the future are still product specific, or where the Member States have the option to retain a certain element of support coupled in the future. Such possibilities have in particular been foreseen in the area of animal premia (beef and sheep), where the concern with regard to the effect on production and decoupling has been most pronounced.

Notes

1. Other countries around the world criticize the CAP for its unfair subsidies, its contribution to global price collapses and its dumping practices.
2. Agriculture is a major resource for these countries and will impact the overall dynamic of agriculture in the EU.

3. Indicative price is the price that the European authorities assess for the transactions, limit price is the minimal price that imported products can be sold, intervention price is the guaranteed price that an intervention organism designated by the member states buys the products and stores them.

4. Taken from Mariam Fisher Boel's speech, "Farming for the Future," Birmingham, 26, February 2007.

5. Friends of the Earth Europe et. al. "Rethinking the CAP." November 2005. http://www.foeeurope.org/publications/2005/re-thinking-the-cap_Nov2005.pdf

Part III
Case studies on soil protection in Mediterranean agri-environments

Is soil erosion in olive orchards as bad as often claimed?

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Abstract

Erosion rates in olive orchards on sloping and mountainous land have been mentioned to be of important concern, with some regional averages supposedly as high as 40 – 100 ton ha^{-1} y^{-1}. This claim has its roots in empirical models that apply a simple multiplication of adverse environmental factors such as steep slopes, erodible soils and low soil cover by frequent tillage. We present experimental data from rainfall simulations, runoff plot studies and field assessment of erosion symptoms that challenge this conventional view. Seven reduction factors (inter-)acting at different scales are identified that play a role: 1) tillage increases surface roughness and infiltration; 2) rock fragment cover protects the soil and reduces the slope effect on erosion; 3) orchard undercover reduces sediment losses; 4) long-term erosion creates a non-uniform slope that allows infiltration of runoff; 5) cover strips obstruct the formation of rills and gullies; 6) erosion mainly results from rare high intensity rainfall events, and 7) upscaling of experimental results leads to over-estimation of erosion.

Although each reduction factor pertains to a certain scale of analysis only and affects erosion processes differently, together they argue for better indicating when, where and for whom erosion constitutes a problem. A literature review (of various types of assessments) yielded erosion rates spanning a range of over a factor 10 000. In some individual experiments differences between treatments (tillage versus non-tillage or cover strips) were still a factor 100, frequently to the disadvantage of tillage operations.

Our results indicate that soil loss from runoff plots (7.5 x 15 m, previously tilled) after cumulative rainfall of 104 mm was 17.3 g m^{-2} for non-tilled against 8.5 g m^{-2} for tilled conditions ($P<0.05$) . In another runoff plot experiment (10 x 22 m, previously under a cover crop), tillage led to initially higher soil loss, but

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differences rapidly disappeared. Rainfall simulations on soils with plant cover had significantly lower soil loss than those without plant cover (recently tilled) (61 g m^{-2} versus 218 g m^{-2}, $P<0.001$); runoff however was not significantly different. Consecutive rainfall simulations on soil with rock fragments in place and removed resulted in significantly lower runoff, runoff coefficients and soil loss ($P<0.01$) in the case with rock fragments. On non-uniform slopes runoff and soil loss were spatially different, and tillage led to variable responses depending on location.

Combining findings from separate experiments, we conclude that tillage applied wisely in selected locations of an orchard might reduce erosion. Localized erosion may still be controlled at field level by vegetative strips. Based on results from this study, average soil erosion rates are unlikely to surpass 10 ton ha^{-1} y^{-1}, which is nevertheless still more than the tolerable soil loss of 1 ton ha^{-1} y^{-1}. Any recommendations for improved soil management should ideally be tested at the appropriate scale and should capture the climatic (rainfall) conditions for which they are intended to mitigate soil erosion problems.

Keywords: Soil erosion; Mediterranean; Cover crops; Rock fragments; Tillage; Non-uniform slopes

Introduction

Soil erosion is a highly variable process in space and time that has intrigued many scientists and worried land managers and authorities. Both put high importance on predicting where it will occur, what impact it will have and where and how it can be controlled. In attempting to promote more sustainable soil management practices, policy-makers have taken refuge to simple empirical regression models such as the (Revised) Universal Soil Loss Equation (NRCS-RUSLE2, 2006) in order to design policies. While these models have often only been validated to limited extent, their predicted erosion rates are treated with a great deal of authority. An illustrative example of this is found in olive orchards.

Olive orchards are an important land use in the Mediterranean region, especially on sloping and mountainous land prone to soil erosion. According to many scientists, erosion is the major problem associated with olive (*Olea europeae*) cultivation (Tombesi et al., 1996; Guzmán Álvarez, 1999; Beaufoy, 2001; Pastor et al., 2001). Olive orchards have been assessed to have the highest erosion rates in the region attributed to them (e.g. Pastor and Castro, 1995; Schoorl and Veldkamp, 2001). The frequently cited average soil loss estimate of 80 ton ha^{-1} y^{-1} for Andalusian orchards is based on a coarse-scale USLE model estimate by Lopez-Cuervo (1990), disregarding the author's mention that within-field sedimentation was not accounted for (Gómez et al., 2005). Similarly, ICONA (1991) and Kok et al. (1995) report USLE-based average soil erosion estimates of 95 and 40–100 ton ha^{-1} y^{-1} respectively for Spanish olive orchards. The fact that olive orchards can often be found on steep slopes (Fleskens and de Graaff, 2003) seems to have led to the widespread belief that soil erosion thrives in olive orchards. Moreover, trees in rainfed orchards on steep slopes are widely spaced and farmers preferentially apply intensive tillage to keep orchard soils free from weeds (de Graaff and Eppink, 1999; Zobisch and Masri, 2000).

It seems however too simplistic to develop policies based on the above generalities. Olive orchards come in many varieties, with those on the steepest slopes often under better land husbandry practices such as terraces (Fleskens, submitted). In fact, some steepland olive orchards are recognized as sustainably managed (Kosmas et al., 1997; Loumou and Giourga, 2003). On the other hand, orchards on gentle slopes have been reported to suffer substantial erosion, i.e. above a tolerable soil loss of 11.4 ton ha^{-1} y^{-1} on a 3.4% slope (Gómez et al., 2003). What is more, as already touched upon while discussing Lopez-Cuervo's 80 ton ha^{-1} annual soil loss estimate, there is an important scale effect in measuring erosion, as it involves processes of detachment, entrainment, transport and sedimentation that are respectively best assessed at scales of less than one square meter to several tens of hectares or even square kilometres (Stroosnijder, 2005). Consequently, high within-field soil loss rates do not necessarily create important off-site problems at the catchment level. The question whether the soil erosion record of olive orchards is 'bad' thus includes a reference issue, a scale problem and an evaluative dimension.

The purpose of this paper is first to provide a context on available soil erosion estimates for olive orchards; second to present reasons why soil erosion rates might be lower than often claimed (addressing the abovementioned reference issue and scale problem); and third to discuss the implications for soil conservation practices and policies (addressing the evaluative dimension). The first objective sets the stage and will be embarked upon in the remainder of this introduction. In the next section field research methods are described and subsequently results are presented and discussed. Results are presented according to possible causes for overestimation of erosion in the form of so-called reduction factors. Finally, concluding remarks on the implications of these findings complete the paper.

Table 1 summarizes data on erosion rates measured in olive orchards. A few warnings should be given: a) some data refer to simulated single events, others to average annual values calculated from multi-year experiments; b) although soil loss data are expressed in g m^{-2} as the most appropriate unit for the majority of experiments (and of those to be presented in this paper), methods vary widely and results are in principle not comparable; c) differences between treatments can be compared taking into account possible (minor) scale differences.

Taking into account the above limitations, we see that soil loss rates reported easily differ a factor 10 000. The influence of slope, vegetative cover, rock fragment cover, soil type, presence and state of soil and water conservation measures, and amount and intensity of precipitation certainly play a role, but cannot account for differences this large: differences between treatments (aggregated under the headings conventional tillage – CT; no-tillage – NT; and cover crop strips – CS) usually do not differ more than a factor 100. The 'unexplained' differences (also a factor 100) may be illustrative of the suggestion that assessment of soil erosion rates will always be biased to methods and scales of analysis employed (Stoosnijder, 2005).

Theocharopoulos et al. (2003), who assessed erosion rates with ^{137}Cs at catchment level, estimated that the net soil loss from the catchment amounted to 18–22 ton ha^{-1} y^{-1}, while soil erosion rates measured at various points within the catchment varied between 4.5–96 ton ha^{-1} y^{-1}. This difference could be explained by sedimentation, ranging from 1–189 ton ha^{-1} y^{-1} at different points in the catchment. Failure to take into account sedimentation is but one problem with erosion prediction approaches. Gómez et al. (2003) mention too simple soil cover (C-factor) estimates as a second reason for over-estimation of erosion by USLE-based studies and propose an approach of evaluating soil cover at 15-day periods. They show that soil management systems importantly influence soil erosion rates, from a minimum of 15 ton ha^{-1} y^{-1} for a barley (*Hordeum vulgare*) cover crop to a maximum of 80 ton ha^{-1} y^{-1} for a no-till bare soil situation in an orchard on a 70 m long 20% slope. According to Gómez et al. (2005), further reductions are to be accomplished by taking into account the protective effect of rock cover (Poesen et al., 1994), a common characteristic of the sloping Mediterranean environments.

Concentrating on the plot (<225 m^2) and field (2500 m^2) scales, we present experimental results that allow us to distinguish seven factors why erosion rates in olive orchards are often exaggerated:

1. Tillage increases surface roughness and infiltration
2. Rock fragment cover protects the soil and reduces the slope effect on erosion
3. Orchard undercover reduces sediment losses
4. Long-term erosion creates a non-uniform slope that allows infiltration of runoff
5. Cover strips obstruct the formation of rills and gullies
6. Erosion mainly results from rare high intensity rainfall events
7. Upscaling of experimental results leads to over-estimation of erosion.

Table 1. List of erosion assessments carried out in olive orchards with different methods, specified according to soil management (CT = Conventional tillage; NT = No-tillage; CS = Cover strips).

			Tree		Spatial scale		Temporal scale		Erosion		
Location [reference]	Soil type (Clay-Silt-Sand %)	Slope (%)	- density (ha^{-1})	- age (y)	Dimensions (m)	Trees (no.)	Duration	Precipitation (mm)	CT ($g•m^{-2}$)	NT ($g•m^{2}$)	CS ($g•m^{-2}$)
1. Rainfall simulations											
Cordoba, ES [1]	Colluvial slope (17-16-67)	20	333	15	10 x 12	4	2254s	21.4	121		
		20	333	15	10 x 12	4	1035s	11.6		27	
		20	–	–	0.20 x 0.36		30 min	75	1681;2099	147;290	
		20	–	–	0.20 x 0.36		30 min	83	265[a];1300[b]	74[a];284[b]	
Cordoba, ES [2]	Typic Xerofluvent (s. cl-loam)	7	278	5	8 x18	3	0.79 h	34; 31	30		4
	id.	7	278	5	8 x 18	3	1 h	45; 48			3; 12
Mação, PT [3]	Lithic Xerorthent				1 x 1				23–48	0–75[c]	
2. Field surveys & radio nuclide tracer studies (^{137}Cs)											
Cordoba, ES [4]	Typic Pelloxererts (clay)	13		65	30; 85	10–20[d]			10500;6000		
	id.	10		55	40	id.			6500		
	Typic Xerorthent	33		65	25; 70	id.			7000; 8000		
	Typic Xerochrept (high Ca)	17		100	60	id.			7000		
	Typic Pelloxererts (43-41-16)	13		65	220[e]				8440 (0-22300)		
3. Runoff plot studies											
Lesvos, HE [5]	?	50			10 m^2		2 y		0.056	0.024[f]	
Athens, HE [6]	Typic or Calcic Xerochrept	16–23			3 x 10		5 y	496 (349–575)		0–3[g]	
Cordoba, ES [7]	Typic Chromoxerert (49-47-4)	13.4	278	7	6 x 12	2	3 y	665 (594–744)	400	850	120

Cordoba?, ES [8]	?	30					2 y			2510	740;1030
Cordoba, ES [9]	?	13					1 y		5000		50
		4					1 y		300		20
Calabria, IT [10]	?	?					2 y		4100	36[h]	
Sevilla, ES [11]	Typic Xerochrept (29-29-42)	6	204		1 x 8	0	2 months	204	4.6		0.3
	Typic Calcixerept (19-9-72)	5	204		1 x 8	0	2 months	204	0.4		
	Aquic Haploxerept (31-17-52)	7	204		1 x 8	0	2 months	180[i]	8.2[i]		
Granada, ES [12]	Typic Xerochrept	30		25			>1 y	571	1010	4250	340
Granada, ES [13]	Typic Xerorthent (19-27-54)	30	156	30	8 x 24	3	2 y	270;460	100;1040	1050; 4070	170;240
Lesvos, HE [14]	(clay or clay-loam)	25; 40			10		2 y	481		1; 5	
Aleppo, SY [15]	Lithic Xerorthent (25-40-35)	24		80			4 y	400–650	1190–8100	20–1410	

References: [1] Giráldez et al. (1990); [2] Castro et al. (in press); [3] Coelho et al. (2001) cited in Carvalho et al. (2002); [4] Laguna & Giráldez (1990); [5] Arhonditsis et al. (2000); [6] Kosmas et al. (1997); [7] Gómez et al. (2004); [8] Arroyo (2004) cited in Gómez et al. (2005); [9] Gómez et al., unpublished (Gómez et al., 2005) ; [10] Raglione (1999) cited in Gómez et al. (2004); [11] De la Rosa et al. (2005) ; [12] Francia Martínez et al. (2000); [13] Francia Martínez et al. (2006); [14] Koulouri & Giourga (2006) ; [15] Bruggeman et al. (2005). Notes: [a] Under canopy; [b] Open field; [c] Treebase measurements; [d] ^{137}Cs study; [e] Soil cover range 10–60%; [f] Abandoned field; [g] Soil cover 90%; [h] Permanent cover crop; [i] Same series of events as in other soil types, except for one missing event.

Materials and methods

1. Study areas

Field research focused on three areas: Trás-os-Montes (north-eastern Portugal), Granada (southern Spain), and Basilicata/Salerno (southern Italy). Trás-os-Montes has a continental climate caused by mountain ranges in the West and South that bar Atlantic influences. Of the regional olive area of 72 288 ha (6% of total area), 60% receives less than 600 mm y^{-1} and 90% less than 800 mm y^{-1}(de Figueiredo et al., 2002). At Mirandela (41º29′ N, 7º11′W), the centre of regional olive growing where olives occupy 19% of all land, average annual precipitation is 520 mm. Summer is usually dry. Average annual temperature is 14.1 ºC (January 6.1 ºC, July 23.6 ºC). Soils are less than 0.5 m deep in 76% of olive orchards, and a similar share of orchard soils has a stoniness of over 30% (de Figueiredo et al., 2002).

In Granada, the study area was confined to the agrarian region of Iznalloz (37º23′ N, 3º31′W). Iznalloz has 24 500 ha of olive orchards, occupying 30% of its total surface. It is crossed by the Subbetica mountain chain, and the territory of Iznalloz is at an altitude of 800–1400 m a.s.l. Soils included in the study area are mainly moderately deep Inceptisols and Aridisols with accumulation of calcareous and gypseous materials and low organic matter content, along with shallow Entisols (Xerorthents) in the steepest areas and, less frequently, deep Alfisols with high organic matter content (Aspizua, 2003). Average annual precipitation is between 500–600 mm, falling predominantly in March/April and November/December. Mean temperature is 12.3 ºC (December 5 ºC, July 22 ºC) (Aspizua, 2003).

Two research sites were selected in the Italian study area, respectively at Caggiano (40º34′ N, 15º30′E, elevation 450 m a.s.l.) and Ferrandina (40º31′ N, 16º26′E, elevation ca. 400 m a.s.l.). The two locations are separated by the Lucanian Apennines, causing Caggiano to have a distinctly more humid climate than Ferrandina (average annual precipitation of 866 mm against 676 mm, which is moreover better distributed over the year). Average annual temperatures are 19.3 ºC and 13.9 ºC respectively (January: 10.8 ºC vs. 5.5 ºC, August 30.1 ºC vs. 23.4 ºC) (Xiloyannis et al., 2004). Soils around Caggiano are derived from Appenine rock sediments and have sandy–clay to clayey–sand texture. Topsoil (0–15 cm) texture from a sample of olive orchards was 39% sand, 20% silt and 41% clay, with a soil organic matter (SOM) content of 2.1%. At the Ferrandina-site, fluvial sandy conglomeratic soils predominate (average texture of orchard soil sample: 44% sand, 22% silt, 34% clay; SOM-content 1.2%). Active $CaCO_3$ content is rather high at 7.4% by weight (Xiloyannis et al., 2004). In the Basilicata/Salerno area there are 72 600 ha of olive orchards (7%). The area surrounding Caggiano has a much higher prevalence of olive orchards, while in the Ferrandina region annual crops dominate.

2. Rainfall simulations

A total of 160 rainfall simulations were performed with a mobile rainfall simulator (Kamphorst, 1987) at the Italian and Portuguese study areas. The rainfall simulator covers a square surface area of 6.25 10^{-2} m^2. The following types of simulations were done in a temporal sequence (simulations of type 3 and 4 were only performed in Portugal):

1. Simulations under ambient conditions (variable initial soil moisture content and rock fragment cover (n = 63);
2. Simulations under pre-wetted conditions (5–10 minutes after simulation type 1); initial soil moisture content is assumed to be saturation (n = 62);
3. Simulations after removal of coarse (> 2 cm) rock fragments, approximately 30 minutes after simulation type 2 (n = 21);
4. Simulations performed after simulation type 3; generally, the removal of rock fragments exposed dry soil underneath, and also led to the creation of artificial roughness (craters); at the end of simulation type 3, these disturbances were neutralized (n = 14).

Simulations were run for 180 seconds. The time to first runoff (TTFR) was recorded and the amount of simulated rainfall and the volume of collected runoff were registered. The mass of eroded sediment was determined after drying (105 ºC, 24 h).

3. Runoff plots

Runoff plots were installed at Caggiano (Italy) and Mascarenhas (Portugal): 41º33’03”N, 7º08’39”W, 350 m a.s.l. At Caggiano, two bounded plots of 225 m^2 (ca. 10 x 22 m) were constructed on a south facing slope of 32%. Each plot incorporated four olive trees with varying canopy diameter (1–4 m; smaller trees of younger age were planted in between the older trees) in order to represent the orchard situation. Trees are planted in a rectangular pattern at 5 m within-row distance and 10 m between-rows distance. Tree density is thus 200 trees ha^{-1}. At the moment of installation (October 2004), a permanent cover crop (CC) consisting of different types of clovers (*Trifolium* spp.) and herbs had been developing for four years on both plots. The farmer controlled the cover by performing several mowings per year, to serve as cattle feed. For the experiment, the cover crop on one plot was eliminated by tillage (CC-T) in a ploughing operation to 0.25 m depth in order to evaluate the differences in runoff and erosion.

At the lower side of the plots a trough was installed to collect runoff water and suspended sediment which was transported to drums with a storage capacity of 0.5 m^3. The first drum was connected to a second one to which one fifth of the volume in excess of its own capacity was conveyed. With this set-up it was possible to collect up to 3 m^3 of runoff (the equivalent of about 13 mm of overland flow). Measurements of runoff were taken after each heavy rainfall event or after a few minor rain-events in the period November 2004 until February 2005. Runoff volume was, after calibration, directly determined by water height in the drums (regression equation $r^2 > 0.99$). Eroded sediment was determined by taking samples of the water in the drums after stirring, at different height levels. Suspended sediment in the samples was filtered and oven-dried, after which its mass was determined. This method has been applied successfully elsewhere (de la Rosa et al., 2005). Rainfall, temperature and relative air humidity data were measured with a fully automated meteorological station at the site at a sampling frequency of 2 minutes.

In Mascarenhas (Portugal), four runoff plots of 7.5 x 15 m were constructed (July 2004) in an olive orchard with a stony soil under conventional tillage (two ploughing operations per year to 0.15 m depth). The slope of the plots was 18% and the soil depth less than 0.2 m. Rock fragments cover 56% (n = 12, range 46–68% - see Section 2.5 for method) of the soil on the plots. Soil texture was determined: 61% sand, 32% silt and 7% clay. Olive trees are about 50 years old, planted approximately on rows along contour lines at a density of 100 trees ha^{-1}. The entire orchard had been tilled in March 2004. On 22 November 2004, two plots were tilled as customary under conventional tillage (CT), whereas a natural cover crop was allowed to establish on the other two plots that were not tilled (CT-N, with N standing for the natural cover crop that developed). Runoff was collected in reservoirs directly beneath each plot. Reservoirs were made of earth and covered with plastic, with a straw layer underneath to protect the plastic from puncturing. After calibrating each reservoir individually (regression equations $r^2 > 0.99$), runoff volume could be determined by registering the water height. The experimental set-up required some additional calculations: a) subtraction of the amount of rainfall directly collected by the reservoirs; b) if water volumes were not instantly determined: a correction for evaporation was needed. The amount of sediment was harder to determine; several hours after a rainfall event, most sediment had settled at the bottom of the reservoir. Water was then siphoned out of the reservoirs and the remaining sediment was left to dry as much as the weather allowed. Atmosphere-dried sediment was collected with a broom and stored in sealed plastic bags. These were later oven-dried and weighted in the laboratory.

Rainfall was collected at the research site with a tipping bucket rain gauge (0.2 mm tip^{-1}) and registered at intervals of one hour. Additional climatic data in order to calculate potential evapotranspiration (Penman-Monteith method - Allen et al., 1998) were taken from Mirandela meteorological station (distance 7 km).

4. Runoff detectors

A total of 74 runoff detection devices (Fig. 1) were placed on different points of an alternating convex and concave hillslope at Ferrandina, Basicilata (Italy). The

T-shaped detectors, made from PVC tube diameter 50 mm, have openings that allow runoff to enter the horizontally placed section (the catch tube) along a length of 16 cm. The runoff detectors were installed with the incised side in upslope direction and aligned across the expected path of overland flow to catch runoff and suspended sediment. The water captured by the device is subsequently led to the vertical tube (the storage tube) for later observation. While installing the tubes care was taken to: a) avoid seepage of runoff under the catch tube; and b) that a slight inclination of the catch tube allowed collected runoff to enter the storage tube by gravity. Similar runoff detectors have successfully been used to collect information on the occurrence of overland flow (Vigiak et al., 2006). In this research we determined the height of the water column in the storage tube as an indicator of runoff and assessed the amount of sediments by three levels of magnitude (none/low, half-full, full).

The devices were checked for their position and settlement after the first rainfall event, and repositioned if necessary. Thereafter, it has been possible to take three measurements in the period October – December 2004.

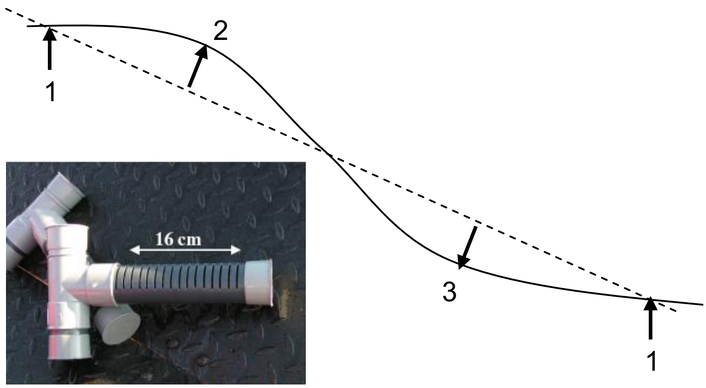

Figure 1: *Runoff detectors and schematic overview of their positions (1–3) along a convex-concave hillslope.*

5. Field assessment of erosion features and additional field measurements

In Iznalloz, Granada (Spain) 25 fields of 0.25 ha (50 m long and 50 m wide) were selected for visual assessment of erosion using the ACED (Assessment of Current Erosion Damage) method (Herweg, 1996). The method involves the identification of biophysical factors influencing erosion (e.g. slope characteristics, vegetation, land management), erosion symptoms (paths of overland flow, rill and interrill erosion) and, most importantly, an estimation of rill and gully erosion by measuring length, depth and width of rills and gullies. Fields were selected according to a strategy allowing the inclusion of: a) areas of different potential erosion risk determined as a function of vegetation, soil and topography, and b) different soil management systems: bare soil (BAR, n = 9; conventional or reduced tillage and no-tillage with recent herbicide application), covered soil (COV, n = 8; cover created by manually distributed stones or natural vegetation; includes no-till systems prior to herbicide application and semi-abandoned orchards), and vegetative strips of natural vegetation, 1–3 m wide, approximately following contour lines (VEG, n = 8).

Rill measurements were also performed in one runoff plot, Mascarenhas, Portugal, at two different moments.

Soil roughness measurements were conducted on the site of the Portuguese runoff plots at two moments, the first after tillage of two of the four plots, the second at the end of the measurement campaign (June 2005). The chain-method (Saleh, 1993) was used to measure surface roughness in any direction relative to plough furrows but in the direction of the hillslope (subsequently referred to as C_r).

Assessments of vegetation cover and rock fragment cover of fields and runoff plots were performed on sample plots of 1 m^2 with a minimum of three replications. For rainfall simulations, a photograph was made of the ground frame (6.25 10^{-2} m^2) and stone surface cover determined with the aid of image processing software.

Results and discussion

1. Reduction factor 1: tillage increases surface roughness and infiltration

Eroded soil collected from runoff plots in Mascarenhas, Portugal is shown in Fig. 2a. Average annual soil erosion (2004–2005) was 60 g m^{-2} y^{-1} with a standard error (SE) of 9 g m^{-2} y^{-1}. A disaggregation of CT and CT-N treatments was possible from the moment of ploughing two of the four runoff plots, late November 2004 (Fig. 2b). Surprisingly at first, erosion measured in the CT-N treatment was higher than for CT, with an average soil loss of 17.3 g m^{-2} (SE 0.5) against for 8.5 g m^{-2} (SE 0.8) CT (difference significant at $P < 0.05$, t-test – equal variances not assumed; t = 9.52, df = 1.67). The explanation was found in the increase of surface roughness by tillage, which was practiced along the contour. Soil roughness measurements made right after tillage to compare the freshly tilled with the non-tilled treatment resulted in a significant (t-test; t = 2.48, df = 23, $P < 0.05$) difference: C_r of 21.1 (SE 1.9) and 15.1 (SE 1.5) respectively. At the end of the season, this difference was still present (t-test – equal variances not assumed; t = 3.59, df = 13.52, $P < 0.01$): C_r of 13.9 (SE 0.5) and 12.1 (SE 0.2). This was quite extraordinary, probably due to absence of high intensity rainfall (a maximum of 4.3 mm h^{-1} was registered in between the two soil roughness measurements) and the low cumulative rainfall of only 104 mm. However, Lampurlanes and Cantero-Martinez (2006) still found significantly higher soil roughness in tilled fields compared to non-tilled fields after 294 mm of rainfall in a similar time span. In any case, under our circumstances, the micro-relief could persist, reducing runoff and consequently erosion.

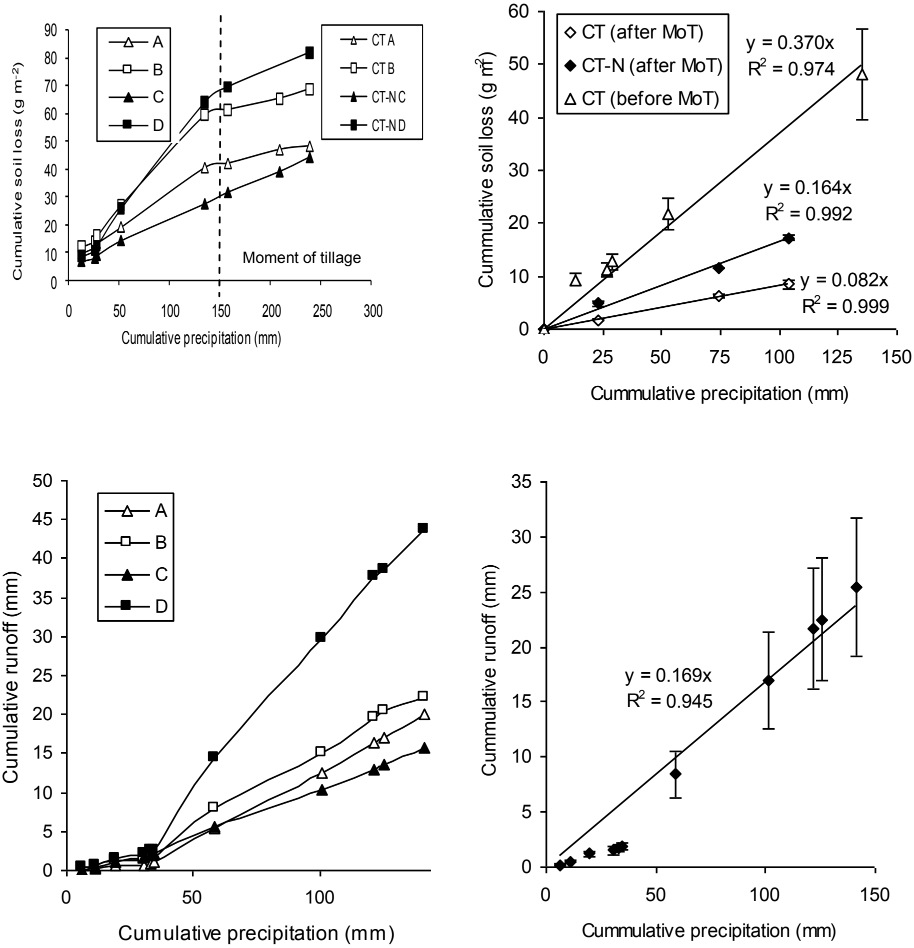

Figure 2. *a) Relationship between cumulative precipitation and soil loss for four runoff plots (Mascarenhas, Portugal); note that tillage (CT) of plots A and B led to a remarkable reduction of the soil loss rate compared to non-tilled plots C and D where a natural cover crop was allowed to establish (CT-N); b) Relationship between cumulative precipitation and cumulative runoff for the runoff plots until the moment of tillage.*

That roughness created by tillage also creates a risk can be illustrated by the data of plots B and D in Fig. 2a–d. Until the moment of tillage, runoff from the latter plot was substantially higher than from the other plots (Fig. 2c), leading to increasing standard errors of cumulative runoff with each observation (Fig. 2d). In plot B, during a moderately intense rain shower, runoff accumulated in the furrow depressions and finally broke through the plough ridge. This triggered the formation of a rill. Rill volume was assessed twice (August and November) and appeared to have slightly (1%) reduced over this period. In plot D, the lower part of the plot had been tilled in the direction of the slope prior to conducting the experiment. A non-parametric test showed that differences between plots in runoff, runoff-coefficient and erosion were statistically significant at $P < 0.05$ in the order D > B > A > C. The differences between plots B and D could indicate that runoff from plots ploughed in the direction of the slope drains excess water with a low sediment concentration, while failure of ridges created by contour tillage might lead to important erosion. The current experiments do not provide sufficient data to test this hypothesis. On top, greater runoff could negatively affect the orchard soil water content and hence orchard productivity.

Tillage delayed the development of a vegetative ground cover, but differences between CT and CT-N plots (20% and 29% plant cover by the end of winter) were not significant. Possibly, the stoniness of the plots obstructed the formation of a continuous vegetative soil cover, so that the role of plant cover in controlling soil erosion maybe severely reduced.

No attention was paid in these experiments to tillage erosion, a process that could lead to considerable relocation of soil (e.g. Govers et al., 1994; Van Oost et al., 2006).

2. Reduction factor 2: Rock fragment cover protects the soil and reduces the slope effect on erosion.

Rainfall simulation plots were selected to evaluate the effect of slope. No significant relation could be found between soil loss and slope gradient. However, a very significant relation (Pearson correlation coefficient 0.415, $P < 0.001$) was found between slope gradient and rock fragment cover. This is in agreement with other findings (e.g. Simanton and Toy, 1994; Poesen et al., 1998).

The protective effect of rock fragment cover was investigated using rainfall simulations (runs 2 vs. 4) ($n = 12$; slope = 24% (SE 3.2%); original rock cover 25% (SE 3.8%)). Runoff, runoff coefficients and soil loss were found to be significantly higher when rock fragments were removed (Wilcoxon Signed Ranks test, $P < 0.01$; Table 2). Cerdà (2001) and Mandal et al. (2005) come to similar conclusions. Although not significant, TTFR was decreased after removal of the stones. Apparently, the stones create extra surface roughness increasing possibilities for ponding, and this effect is stronger than that of raindrops that, when falling directly on stones, cannot infiltrate.

The fact that steeper slopes tend to have higher rock fragment cover, whether a result of past erosion or not, could hence at least partly explain why slope is not the dramatic factor in causing soil loss that is often projected in results from erosion modelling.

3. Reduction factor 3: Orchard undercover reduces sediment losses.

The runoff plots in Caggiano, Italy were designed to evaluate the effect of soil cover. The CC-T plot initially showed erosion rates four-fold higher than the plot under CC (Fig. 3). However, as the experimental season continued, plant cover gradually increased on the CC-T plot. In December, it reached 20%, and in February it was 80%. It is probably due to this development that the difference in erosion between the treatments disappeared. This is in agreement with results obtained by Snelder and Bryan (1995), who noted a rapid increase of erosion rates with plant cover below a critical threshold of 55%. Differences in runoff coefficient were less marked, but seem to remain higher under CC-T than in CC, even after the establishment of plant cover.

Rainfall simulations showed that plant cover was highly effective in controlling soil loss (Pearson correlation coefficient −0.345, n = 48, P < 0.05; see Fig. 4). Differences in plant cover between recently (less than two months) tilled fields and non-tilled fields were very significant (Table 3). Plant cover was significantly related to soil moisture content (Pearson correlation coefficient 0.438, n = 43, P < 0.01). As measurements started in August and continued up to February, this relation illustrates the development of vegetation.

Table 2. Wilcoxon signed ranks statistics of paired rainfall simulations with and without rock fragments (runs 2 vs. 4, Portuguese research area) (n = 12).

	Runoff (l•m^{2})		Runoff coefficient (%)		Soil loss (g•m^{-2})		TTFR (s)	
	Mean	SE	Mean	SE	Mean	SE	Mean	SE
With rock	7.7	1.4	47	8.1	39.0	7.3	36.2	7.6
Without rock	10.9	1.1	69	6.4	70.1	12.6	22.9	5.3
Z	−2.667		−2.667		−2.589		−0.969	
Significance	0.008		0.008		0.010		0.333	

Table 3. Mann-Whitney statistics of rainfall simulations (run 2) on tilled and non-tilled soil (Portuguese and Italian research areas).

	Plant cover (%)		Runoff ($l \bullet m^{-2}$)		Runoff coefficient (%)		Soil loss ($g \bullet m^{-2}$)		Sediment concentration ($g \bullet l^{-1}$)	
	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
Tilled	1	0.4	9.4	).8	48	4.1	218	35	24.0	5.0
	(*n* = 28)		(*n* = 35)		(*n* = 35)		(*n* = 34)		(*n* = 34)	
Non-tilled	45	8.7	8.0	l.0	44	5.6	61	17	6.7	1.4
	(*n* = 21)		(*n* = 31)		(*n* = 31)		(*n* = 31)		(*n* = 29)	
Z	−5.202		−1.111		−0.657		−3.955		−4.662	
Significance	0.000		0.266		0.511		0.000		0.000	

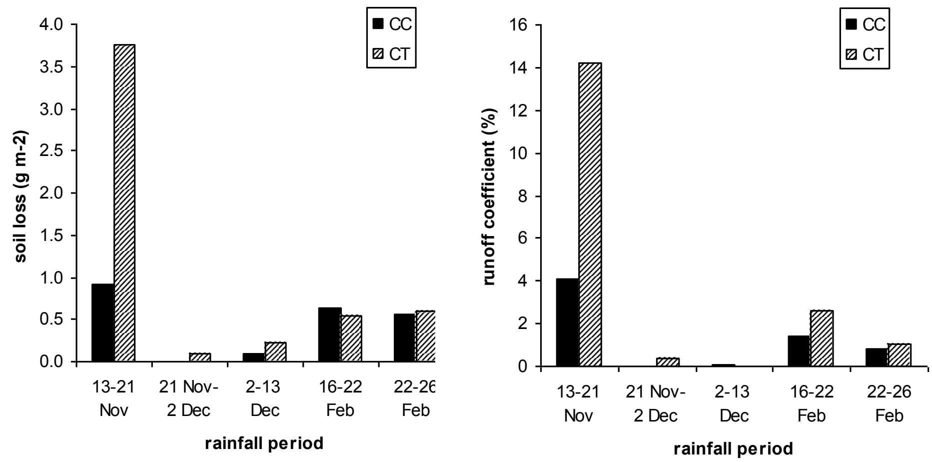

Figure 3: *Soil loss and runoff coefficients measured at runoff plots under permanent cover (CC) or after a single tillage operation (CC-T), Caggiano, Italy.*

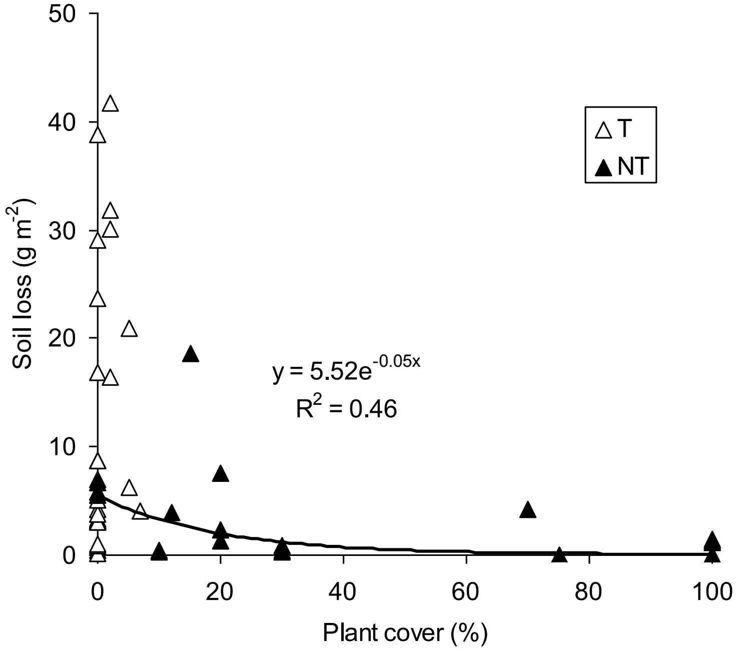

Figure 4: *Relation between plant cover and soil loss as registered in rainfall simulations (runs 2, Italian and Portuguese research areas). NT = Non-tilled ; T = Tilled microplots.*

If we compare runoff and soil loss from rainfall simulations (run 2) on non-tilled (n = 31) and (recently) tilled (n = 34) soil, we observe a non-significant difference for runoff but a significantly lower amount of eroded sediment on non-tilled soil (t-test – equal variances not assumed; t = 4.04, df =47.737, P < 0.001). Under these conditions, with high intensity simulated rainfall and pre-wetted soil, tillage cannot reduce runoff. However, the average soil loss of tilled (218 g m^{-2}, SE 35 g m^{-2}) against non-tilled experiments (61 g m^{-2}, SE 17 g m^{-2}) can be ascribed to difference in plant cover.

4. Reduction factor 4: long term erosion creates a non-uniform slope that allows infiltration of runoff.

Slopes in old orchards are often composed by a sequence of convex-concave slope segments (Fig. 1). At the research site at Ferrandina, Italy, slopes determined at the transition point from concave to convex (1), the point of maximum convexity (2) and the point of maximum concavity (3) were 11, 38 and 36% respectively (Table 4). Slopes at position 1 were significantly different from those in position 2 and 3. Rock fragment cover was significantly higher in point 3. Plant cover was high on position 1, high but highly variable in position 2 and low in position 3.

Results from runoff detectors indicate that runoff accumulates along the slope from position 2, through position 3 to position 1, where after it apparently infiltrates (Table 4). We expected infiltration to occur earlier, between position 3 and 1. A possible explanation for this finding is that the flatter parts of the slope at position 1

Values followed by different letters are significantly different at $P < 0.05$ (Bonferroni-adjusted) have in the past received high amounts of fine-textured sediments, forming a dense layer in or on the topsoil (Verspeek, pers. comm.). Runoff coefficients at position 1 were, despite much lower slope gradient, of the same order of magnitude as those observed at positions 2 and 3. However, this changed when the field was tilled resulting in a large decrease of the runoff coefficient from 46 to 32% (Table 4). Tillage did not lead to reductions of the runoff coefficients at positions 2 and 3. On the contrary, non-tillage was beneficial for infiltration at position 3 (decrease of runoff coefficient from 47 to 23%). This could be associated with erosion-deposition patterns along the slope.

The amount of soil loss in rainfall simulations followed a different pattern. Although considerable runoff was formed at position 1, significantly less soil was eroded. The lower slope and crust formation could be responsible for this. Tillage at this position increased soil roughness and led to even lower soil loss. At position 2, under all circumstances more soil was detached and lost in the rainfall simulations. However, as runoff detectors at this position captured low amounts of runoff and were never found to be filled with sediment, it is postulated that soil loss is transport-limited here. Soil loss at position 3 was importantly influenced by tillage. Runoff detectors at this position were most frequently found filled up with sediment, so that we assume most soil is deposited between points 3 and 1, when runoff velocity is reduced. That means that under non-tilled conditions, this position experiences a net outflux of sediment, leaving little erodible soil available. However, when tilled, soil displacement by tillage is thought to lead to accumulation of soil in this position, so that the availability of erodible soil is increased (Govers et al., 2006).

Table 4. Data of runoff detectors and rainfall simulations (all, untilled and tilled) on irregular slopes in Ferrandina.

	Hillslope position		
	1	2	3
Runoff detectors			
Number of registrations	88	6	112
Water depth in detector (cm)	8.7 a	2.0 b	7.9 c
Sediment count of half-full	2	0	5
Sediment count of full	2	0	9
Rainfall simulations			
Number of experiments	10	14	18
Runoff (l m^{-2})	9.4	10.6	10.1
Runoff coefficient (%)	45.9	52.1	47.2
Soil loss (g m^{-2})	98 a	336 b	253 b
Slope (%)	11.3 a	38.4 b	35.8 b
Rock fragment cover (%)	22.7 a	38.3 a	86.7 b
Plant cover (%)	13.5 a	24.3 ab	2.3 b
Untilled			
Number of experiments	8	6	4
Runoff (l m^{-2})	10.1	10.0	8.4
Runoff coefficient (%)	49.4	50.0	23.3
Soil loss (g m^{-2})	107	194	82
Slope (%)	12.8 a	39.1 b	27.2 c
Rock fragment cover (%)	22.7	15.0	–
Plant cover (%)	15.7	45	–

Table 4 (continued)

Tilled			
Number of experiments	2	8	13
Runoff (l m^{-2})	6.4	11.0	10.7
Runoff coefficient (%)	31.8	53.6	52.7
Soil loss (g m^{-2})	54	445	304
Slope (%)	5.4 a	37.8 b	38.3 b
Rock fragment cover (%)	–	50.0	86.7
Plant cover (%)	7.0 a	3.5 ab	2.3 b

5. Reduction factor 5: cover strips obstruct the formation of rills and gullies.

An important form of erosion in olive orchards is rill erosion. The scale of analysis at microplots (rainfall simulations) and runoff plots does not permit its consideration. The field survey of rills carried out in Iznalloz, Spain (Aspizua, 2003) allows us to make some important observations. Plant cover, at the field scale, varied between 5% and 95% (average 47%). Observed soil loss was only weakly correlated with plant cover (r^2 = 0.18). Fig. 5 shows the importance of the distribution of soil cover by plants as influenced by soil management applied (BAR, COV, VEG). The number of rills observed is significantly different (Kruskall-Wallis, χ^2 = 11.6, 2 df, P < 0.01), although differences between categories individually are not. Next, the average length of rills observed is shown. Differences between treatments are significant (Kruskall-Wallis, χ^2 = 8.0, 2 df, P < 0.05). Rills in the VEG treatment are significantly less long than in the BAR treatment. Also the resulting differences in average soil loss are significant (Kruskall-Wallis, χ^2 = 10.2, 2 df, P < 0.01). Soil losses in BAR, although highly variable, are much higher than in COV and VEG as a result of the cumulative differences in the number of rills, average rill length and moreover average rill depth and width (not shown). Vegetative strips are thus highly effective in controlling soil loss, mainly because the dimensions (especially length) of rills are smaller.

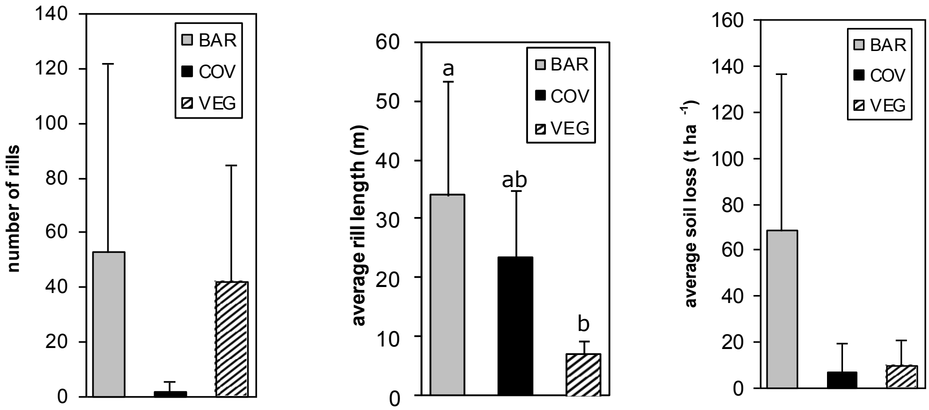

Figure 5: *Data from ACED field survey, Iznalloz: number of rills, average rill length and average soil loss from rill erosion. Bars indicate standard errors. Different letters indicate statistical significance (Bonferroni-adjusted, P < 0.05).*

6. Reduction factor 6: erosion mainly results from rare high intensity rainfall events

A remark about all erosion measurements other than simulations is that much depends on luck to capture high intensity long duration events. Our runoff plot results from Mascarenhas, Portugal, show that the single most erosive rainfall event of which eroded sediments were recorded in isolation accounted for only 10% of total rainfall in the experimental period, but generated 15% of the total quantity of sediment collected. The data of Francia Martínez et al. (2000) show much extremer results. The single most erosive rainstorm (out of 18 registered ones) led to 46% of total erosion of a cover crop (CC) treatment, 66% of total erosion of a no-till (NT) treatment, and 90% of total erosion of a conventional tillage (CT) treatment. Would this event not have been captured, then cumulative erosion for the treatments would only have been 14.4 ton ha^{-1}, 1.8 ton ha^{-1} (13% of NT) and 1.0 ton ha^{-1} (7% of NT) respectively for NT, CC and CT. The conclusions would have been very different than the actual ones of 42.5 ton ha^{-1}, 3.4 ton ha^{-1} (8% of NT) and 10.1 ton ha^{-1} (24% of NT). Not only the absolute values would differ up to a factor 10, but the recommendation of CC as the best soil conservation method would not have hold. This means that any soil management option can only truly be recommended after it has been shown to perform well under extreme conditions.

7. Reduction factor 7: upscaling of experimental results leads to over-estimated erosion.

Upscaling of experimental erosion research has often been indicated as a very precarious process. If we take our basic methods, we have reported results from rainfall simulations, runoff plots and visual erosion assessment (ACED) fields. Spatial scales range from 6.25 10^{-2} m^2, via 114 m^2 and 225 m^2 (runoff plots) to 2500 m^2. Temporal scales should, in the same order, be expressed in minutes, days and months. If we would like to compare the results, we should express them in the same units, e.g. g m^{-2} mm^{-1} (simulated) rainfall. We assume thereby that erosion symptoms observed in ACED plots were created in (less than) one year. To be on the safe side, we left out three fields where gullies (rills deeper than 25 cm) were recorded. Aggregating all measurements, it can be concluded that methods at different scales lead to significantly different results (Welch F-asymptotical 36.1, df1:3, df2: 59.5, $P < 0.001$). The distribution of results per method is different (Fig. 6): rainfall simulations are e.g. characterised by many outliers and extreme values and ACED fields demonstrate large dispersion. While rainfall simulations measure interrill erosion, runoff plots rill- and interrill erosion, and ACED fields only rill erosion, it is rather striking that the method capable of both leads to the lowest estimates. One reason is that rainfall intensity of the rainfall simulation experiments was very high and rainfall intensity captured during the duration of runoff experiments fairly low.

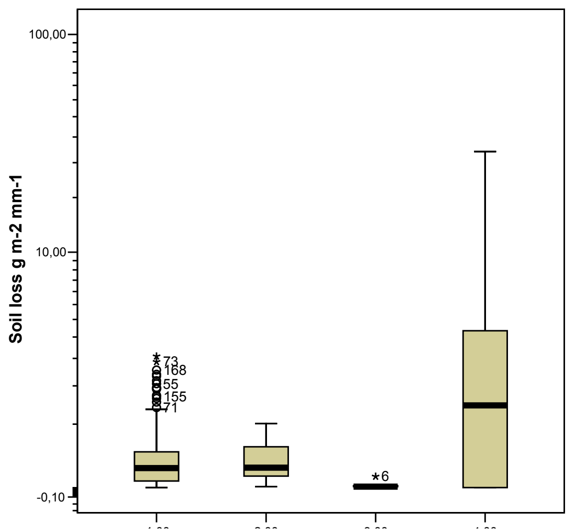

Figure 6: *Box plot of soil loss as a function of experiment (1=rainfall simulations, n = 160; 2 = runoff plots Portugal, n = 32; 3 = runoff plots Italy, n = 10; 4 = ACED fields, n = 25). Different letters indicate significant difference (P < 0.05).*

That further upscaling (to ACED fields) shows a jump in soil loss estimates can possibly be caused by the fact that this method does not consider relocation of sediment within the field. This is a problem inherent to many methods; see for instance the previously mentioned example of Theocharopoulos et al. (2003). This may be illustrative of the need to verify erosion estimates at the (sub-) catchment outlet. This is especially so if erosion estimates are to be used for an assessment of potential off-site effects.

Assuming annual rainfall of 1000 mm (higher than in any of the research sites), average soil loss from our experiments would be 4.4, 3.3, 0.2 and 44 ton ha^{-1} yr^{-1} respectively for rainfall simulations, two types of runoff plots and ACED field assessment. Median soil loss in the same order would be much lower at 2.2, 2.3, 0.1 and 13 ton ha^{-1} yr^{-1}. Considering that soil losses from ACED fields are probably overestimated, erosion rates in the present study are far below average values of 40 – 100 ton ha^{-1} yr^{-1} based on simulation studies. However, tolerable soil losses on steep slopes with shallow soils are low, and any soil loss above 1 ton ha^{-1} yr^{-1} could be considered irreversible within a time span of 50 – 100 years (Van-Camp et al., 2004).

Conclusions

Slope is a less important factor in determining soil erosion in olive orchards than it appears to be in model studies. A first reason for this could be rock fragment cover. Rock fragments protect the soil from the erosive impact of raindrops and reduce the speed of overland flow and there are more rocks on steeper orchards. A second reason is that olive orchards on steep slopes tend to promote the formation of natural terraces. Steep hillsides should in this situation not be regarded as a continuous slope, but as a sequence of sections in which zones of runoff generation and erosion alternate with zones of infiltration and sedimentation.

Tillage is not usually the adverse soil management strategy as frequently referred. First, under low intensity rainfall conditions and not too steep slopes tilled fields allow more infiltration and lead to less runoff and erosion. Second, timely tilled fields may see the quick development of natural plant cover. By the time winter rains start (contributing 30–40 % of total average annual precipitation in the areas studied), the field is well-protected against erosion. The period in which the field remains bare or poorly covered is short.

This leads to two recommendations: tillage can be a useful practice in controlling erosion. By its wise application in designated zones, i.e. at the point of transition from convexity to concavity in non-uniform slopes, infiltration can be enhanced.

Erosion in Mediterranean environments is mainly caused by rare high intensity rainstorms. Although the use of cover crops is widely advocated given their success under normal circumstances, their capacity for soil conservation under extreme conditions should be known to assess their real benefit.

Additionally, soil management options should be evaluated on other than erosion aspects. Their effects on the orchard water balance and olive tree productivity should be assessed simultaneously. Other issues, such as reduction of wildfire risk by tillage and biodiversity conservation by (natural) plant cover also need to be integrated.

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Cross-compliance for erosion control in olive orchards on sloping land

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Abstract

Under the past Common Agricultural Policy (CAP) olive oil subsidy regime, farmers were eligible for subsidies on the basis of the amount of olive oil they produced. This led to an intensification of production, particularly on flat land, and had in most cases negative environmental effects, such as more pollution and more soil erosion on the sloping land.

With the decoupling of the agricultural support under the newly established rules of the CAP, formalised in 2005, cross-compliance has become obligatory. Olive producing countries have recently enlisted the obligations farmers have to fulfil in order to be eligible for the full amount of the decoupled support. In case of non-compliance some annually increasing deductions will be applied, and only after several years farmers risk to lose their support rights all together.

On steep slopes erosion control measures should be undertaken, like cultivation along the contour line, minimum tillage, cover crops, maintenance of terraces, etc. Most countries prescribe the last two measures in the cross-compliance obligations.

Farmers on these steep slopes are already confronted with relatively high production costs and low yields and often negative gross margins. They will not be eager to engage in such obligatory measures, since the additional costs are much higher than the initial deductions in subsidy payments they could face.

A linear programming model was developed, to assess the various socio-economic and environmental effects of different development scenarios of olive orchards, as a result of changing market prices, wage rates and subsidies. This included shifts towards intensification, abandonment and organic farming. In the model attention was also given to the likely percentage adherence to cross-compliance. The model showed that cross-compliance obligations may lead to more abandonment and may restrain a move towards more intensive systems.

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In the paper attention is focused on the application of cross-compliance for soil erosion control (natural cover crops and terrace maintenance) in hilly and mountainous olive orchards in Trás-os-Montes in Portugal.

Introduction

During the three year period 2003-2006 the EU project OLIVERO has undertaken physical and socio-economic research on Sloping and Mountainous Olive Production Systems (SMOPS) in five target areas in southern Europe (OLIVERO, 2006). In these target areas 24 different SMOPS were distinguished, with their productive, ecological, economic and social functions (Metzidakis, 2004), and these were grouped into five major types: traditional, semi-intensive low input, semi-intensive high input, intensive and organic production systems (Fleskens, 2005).

While analysing the future perspectives of the SMOPS, several key issues were distinguished that would need to be tackled for the future development of these production systems (de Graaff, 2005). Local olive sector specialists often mentioned soil erosion as a major key issue, next to other problems, such as pests and diseases, low productivity, financial losses and pollution (Fleskens and de Graaff, 2006).

Among others for environmental and social reasons proposals were made in 1997 for changing the EU support policies for the olive sector (EC, 1997). After a long period of preparations and negotiations, new policies were announced in 2003 (EC, 2003), and these were implemented starting in 2006 (EU Council Regulations No. 2183/2005 and 1782/2003). These policy changes may have important consequences, in particular for the small traditional or semi-intensive olive farms, which have no opportunity anymore to increase subsidy payments by increasing production, and have now to comply with obligatory cross-compliance regulations.

Background about policy changes

Production aid has been the main Common Agricultural Policy (CAP) tool to support olive farmers' income, particularly after 1998 when, after a transitional reform of the Common Market Organization (CMO), it became linked to current output for each producer. Under such a support scheme there was a clear incentive to intensify production and small producers in marginal areas, with old less productive trees and no access to irrigation, were at a disadvantage (Duarte et al., 2006). With production intensification negative environmental effects (e.g. erosion, decreased biodiversity, high water use and pollution) became a main feature of many olive growing areas in Spain, Greece, Italy and Portugal (Beaufoy, 2001). Suggestions have been made to revise the subsidy system in such a way as to consider both production and environmental aspects (de Graaff and Eppink, 1999).

In 2004 the olive and olive oil regime changed, with the integration of the support to olive farmers in the Single Payment Scheme (SPS), following a pattern similar to the one introduced in 2003 for the main arable crops.

Under the new rules entitlements were decoupled from current production and would become fixed amounts per year, equal to at least 60% of the average production aid payments during the four-year reference period (1999 to 2002). The remaining part (up to 40 %) was supposed to be retained by Member States as national envelopes, to be distributed as an aid per olive GIS ha, to at the most five categories of olive groves with relevant environmental/social functions.

However, by now all major producing countries (except Spain) have decided in favour of total decoupling, meaning the full integration of the olive support in the SPS.

According to de Graaff et al. (2006), the partial decoupling could have contributed, among others, to the following social and environmental purposes:

- To avoid environmental harm to abandoned plantations
- To assure that traditional farmers in remote areas, with few employment opportunities, could stay in (the olive) business.
- To avoid massive abandonment and/or social isolation in such areas.
- To maintain some standards of bio-diversity and landscape management.
- To establish cost-effective soil erosion control measures on steep slopes
- To control pollution and efficient water use on irrigated SMOPS.To focus on Integrated Pest Management (IPM), and integrated systems.

Because of the choice made for total decoupling some of these purposes, in particular the environmentally oriented, can now only be achieved through (the modest funds for) agri-environmental measures or through cross-compliance requirements.

In fact, with the integration in the SPS, cross-compliance has become obligatory. As for other crop or animal production, olive growers will only be able to benefit from support if they comply with certain rules of good agricultural and environmental practices, defined by each Member State.

Objectives of paper

In this paper we investigate which cross-compliance regulations are being applied or considered with regard to erosion control in olive orchards in different countries, what cost and benefit repercussions this will have for small olive farmers on sloping land, and what effects cross-compliance obligations will have on the respective production systems, with their income and environmental features. This will be illustrated by a case study in Trás-os-Montes in northeast Portugal. Use will be made of a linear programming model to simulate alternative scenarios.

Cross-compliance aimed at soil erosion control in olive orchards

Cross-compliance stands for interlinkage and means that conservation objectives are linked to access for a vital input (e.g. irrigation) or, in this context, that access to certain farm programme benefits is made contingent upon installing erosion-control practices on erodible lands (Shiferaw and Holden, 2000).

While direct subsidies can distort price signals and negatively affect the environment, the idea is that the combination of subsidies with cross-compliance rules for conservation could be beneficial for both socio-economic welfare and the environment.

Under the new SPS policy, farmers may receive payments provided that they maintain their land in good agricultural condition and comply with the standards on public health, animal and plant health, the environment and animal welfare (EU Council Regulation No 1782, 2003).

If a farmer fails to comply with these rules through negligence, direct payments may be reduced by between 5 – 15 %, and in case of deliberate non-compliance, payments may be reduced by at least 20 % and eventually up to 100 % (Martinez Raya, 2006).

Cross compliance in general and for olive orchards in particular is aimed at:

1. avoiding soil erosion; 2. maintaining soil organic matter content; 3. maintaining soil structure; 4. ensuring proper maintenance of land and landscape, and 5. avoiding degradation of habitats.

Although the second, third and fourth aims also relate indirectly to soil erosion risk, we will focus mainly on those cross-compliance regulations that have a direct relation with soil erosion risk in olive orchards.

In Andalucia in Spain the following regulations have been established for avoidance of soil erosion (Consejería de Agricultura y Pesca, 2005; Boja No. 1330):

- Tillage cannot be applied on plots with slopes of or above 15 %; Tillage can be substituted by clearing.
- When the soil is kept bare under the trees by means of herbicides a vegetative band has to be kept along the contour lines for plots with average slope above 10 %
- Grubbing out of trees is not permitted on plots with slopes above 15 %, except when these are replaced by other trees.
- Terraces must be kept in good state of conservation, with good draining capacity and without gullies. After exceptional rains a period of one year is allowed for reparation.

In Greece a total of 17 cross-compliance rules for olive orchards are mentioned, three of which relate directly to soil erosion:

- On land with slopes above 10 % a vegetative cover should be kept during the rainy season;
- On land with slopes above 10 % tillage should be practiced along the contour lines or diagonally. Alternatively vegetative strips should be established to control runoff. Additionally, irrigation should not be applied through flooding
- Stone terraces or natural vegetation in hedgerows of parcels should not be destroyed or removed.

In Italy erosion-related regulations are different per region and the text is rather long, but it can be summarised (for Basilicata region) as follows (Legge Regionale, no. 13, 22-02-2005, art.9; and Decreto 15-12-2005 no. 4432):

- On sloping land, not permanently covered, drainage canals have to be established to properly evacuate surplus water. In Basilicata province it is specified that these canals should not be further apart than 80 m.
- On land with slope above 8 %, as alternative to drainage canals, grass strips could be established along the contour lines, which should not be wider than 5 m and not further apart than 60 m.
- Prohibition to eliminate existing terraces and to carry out unauthorised levelling.

In Portugal the regulations were not yet established in March 2006, but are likely to resemble those for arable crops and follow earlier rules (Despacho Normativo No. 7/2005):

- Parcels should have (natural or seeded) vegetative cover between 15th November and 1st of March of the following year;
- Olive orchard grubbing out must be authorised by Ministry of Agriculture Municipality Delegations.
- Existing terraces should be properly maintained.

Consequences of application of cross-compliance

Leaving out the drainage canals, one could summarise that the obligatory cross-compliance for farmers on sloping and mountainous land will generally concern:

1. a reduction of tillage, with or without temporary cover crops or strips

2. a restriction with regard to grubbing out of old and unproductive trees
3. efforts to properly maintain existing terraces

The application of specific measures to comply with cross-compliance may involve additional costs and/or could have an effect on crop yield and farm income. This will be analysed hereunder for the three major requirements.

Tillage and cover crops

An analysis of the effects on reduced tillage costs and benefits (yield changes) was made in the framework of the EU Olivero project (Martinez Raya, ed., 2006). This yielded some indicative cost figures for three different target areas in southern Europe (Tables 1 and 2). Table 1 shows the effects of this change of management for four different SMOPS in the Granada and Jaen target area, for which soil erosion was a key issue.

It shows that the costs could actually decrease, since the costs of tillage are higher than those for temporary cover crops (killed in spring). But in the semi-intensive - low input systems the yields and the gross margins are also likely to decrease. In traditional systems on very steep slopes it was found that yields may increase with cover crops and that the gross margin may become less negative. But because of the negative gross margins many traditional olive orchards are not properly managed and these farmers do not easily change their management practices.

Thus, only the semi-intensive high input orchards in this area are likely to benefit from the change. A cover crop will reduce costs and this will not affect yields, thanks to the supplementary irrigation, now often applied in these systems, and made possible on sloping land since the introduction of drip irrigation.

The effects of no-tillage on soil erosion can be impressive, but these effects are much less under conditions of heavy rainfall.

In the target areas in Tras-os-Montes and Crete soil erosion was the major key issue for only a few SMOPS. Instead of tillage, herbicides or integrated weed management were used. Table 2 shows that for the (table) olive orchards in Tras-os-Montes this change increased costs and made gross margins more negative. However for the two systems in Crete the change appears to be quite positive, thanks to cost reductions and yield increases, which in the latter case are made possible by irrigation.

The figures in these two tables show that it is on forehand not clear whether the net benefits from no-tillage will turn out positive or negative.

Table 1. Effects of application of no-tillage on erosion, yields and gross margins within four different olive production system on sloping land in Granada-Jaen area

Situation	Erosion	Yield	Tillage	Covercrop	Total cost	Gross Margin
	T ha^{-1}	T ha^{-1}	€ ha^{-1}	€ ha^{-1}	€ ha^{-1}	€ ha^{-1}
GJ-4: traditional system- very steep slope						
Current	263	1.5	76.9	-	1078.9	- 179
Improved	15-210 *	1.6	-	59.1	1061.1	- 101
GJ-3: semi-intensive –low input – steep slope						
Current	128	2.0	60.4		996.5	203
Improved	10-77 *	1.9		45.4	981.6	158
GJ-1: semi-intensive –low input						
Current	35	2.5	41.1	-	1036.0	464
Improved	5	2.4	-	31.7	1026.6	413
GJ-2: semi-intensive –high input						
Current	37	4.0	49.1		1640.1	760
Improved	6	4.0		31.7	1622.7	777

Source: Martinez Raya, 2006.

Note: Area wise GJ-1 and GJ-2 are the dominant SMOPS

* Largest figures in case of heavy rainfall

Table 2. Effects of application of no-tillage on erosion, olive yields and gross margins within three different olive production system on sloping land in Tras-os-Montes and Crete

Situation	Erosion	Yield	Tillage	Weed mgt	Total cost	Gross Margin
	T ha^{-1}	T ha^{-1}	€ ha^{-1}	€ ha^{-1}	€ ha^{-1}	€ ha^{-1}
	PT-3: semi-intensive-high input table olive system – Tras-os-Montes					
Current	-	4.0	73.2	-	1845	- 245
Improved	-	4.0	36.6	76.2	1882	- 282
	HE-1: traditional system Crete					
Current	5	1.85	49.1	84.5	1123	-198
Improved	3	2.03	-	84.5	1074	- 56
	HE-3: intensive system Crete, with integrated crop management					
Current	8	6.5	61.6	168.5	2684	825
Improved	5	6.7	-	177.1	2631	984

Source: Martinez Raya, 2006.

Grubbing out and replacing old unproductive trees

Most of the olive orchards on sloping and mountainous land, and certainly the traditional ones, are old, often exceeding 50 years. These old trees accumulate more wood, provoking a gradually decreasing leaf/wood ratio with lower harvests. Farmers are not allowed to uproot them, unless they obtain permission and undertake replanting. An alternative is rejuvenation pruning. The cost of the pruning are estimated in Spain at 630 € ha^{-1}, and after the pruning harvests will be low for about two to three years. Thereafter yields could be 30 - 50 % higher than before the operation. Besides in some cases the wood could be sold as firewood (Martinez Raya (ed), 2006). While this operation seems beneficial, it requires sufficient capital resources, rendering it difficult for small farmers.

Construction and maintenance of terraces

Construction of terraces can considerably reduce erosion, since it decreases slope length, diminishes surface runoff and favours the infiltration of water. However their construction is very expensive. On such slopes construction costs, with use of bulldozers, are in Greece and Spain respectively around 2000 to 4000 € ha^{-1} (Martinez Raya, 2006). Terraces can also make mechanical cultural practices more difficult, and it requires the necessary maintenance to keep the banks intact and eliminate or reduce weed growth on the risers. Lack of maintenance can eventually cause the collapse of terraces and generate even more erosion. Annual maintenance of terraces is usually estimated at about 5 % of construction costs, or 150 € ha^{-1} on average. This corresponds with the amount of 132.22 € ha^{-1} of agri-environmental aid that can be obtained for this purpose, or for sustainable olive growing on steep slopes in general.

Consequences for SMOPS

These three cross-compliance requirements constitute both important changes in management and often also additional costs that are not always compensated by benefits. The question is to what extent farmers will take the risk not to comply, if they are of the opinion that these are not in their short-term interests. This will be discussed in the following case study.

The case study area in Portugal

In the North East of Portugal, Trás-os-Montes represents around 22 % (72 288 ha) of the national olive orchards' area and it is the region with the largest number of olive holdings (37 344). It has over the years 2002-2004 also been the main Portuguese olive oil producing region with about 33 % of national production (INE, 2004 and 2005). Olive orchards account for 16.5 % of the regional Usable Arable Area, but in some municipalities this share is above 40 %.

However, few farms in Trás-os-Montes are specialist olive growing farms. In fact only around 16 % of the farms and 29 % of olive orchard's area belong to this type of farms. Most farms have also other enterprises, such as other permanent crops (e.g. vineyards) or sheep. The average olive orchard's area is only 1.94 ha, although in Mirandela, where olive orchards represent 44 % of the Usable Arable Area (UAA), average olive orchard area is 3.4 ha.

This low average orchard's area confirms the predominance of very small olive producers, those having less then 5 ha of olive grove, that represent 93 % of the number of farms and 56 % of the olive orchard's area. For most of these producers income comes mainly from off-farm activities, while for the small number of medium and large producers (those with more than 10 ha of olive orchard) income comes mainly from agriculture and particularly from olive growing.

Being a low-income region where industry is almost absent, Trás-os-Montes has a regional economy highly dependent on agricultural production. Olive production systems strongly contribute to regional income generation, and employment, not only directly from olive farms, but also through the processing units and services associated. These contributions help to secure the liveability of a region with a declining population, relatively high levels of illiteracy and unemployment (Duarte et al., 2006).

From the five SMOPS identified in Trás-os-Montes, the traditional system associated with a low plant density, old or very old trees and low productivity is the most represented (Figueiredo et al., 2002). This system has important environmental and social functions, such as preventing fire risk, contributing to biodiversity enhancement, and being a complement of income for many small or very small producers (Duarte et al., 2006a).

Beyond demographic factors like the absence of a successor, the total decoupling, as previously discussed, may increase the risk of abandonment that farmers are already facing. So, in this context, specifying the appropriate cross-compliance rules could possibly contribute to prevent the negative environmental and social effects of abandonment.

Future scenarios, with linear programming model

In order to assess the future development of the respective SMOPS, under different assumptions with regard to subsidies and olive oil prices and wages, the Olivero project has developed a linear programming model (Fleskens and de Graaff, 2006).

The linear programming simulation model was developed, with the use of GAMS (Brooke *et al.*, 1998), to assess the various socio-economic and environmental effects of changes between different SMOPS types, including abandonment. While aiming at the highest possible annual net returns from olive production over the period 2005 – 2030, the model includes various constraints, such as constant total area, limited family and hired labour supply, minimum return to labour, annual amount of finance for investment, time lap for production changes, subsidy levels, budget for agri-environmental measures, etc. For convenience reasons it consists of a hypothetical area of 10 units (ha or 1000s of ha), at the start showing the 2005 distribution of SMOPS as existing in the target area. Influencing variables are the level of subsidies after 2013, the labour cost and olive oil prices. The model includes various environmental indicators that are affected by the changes of SMOPS, such as soil loss, wildfire risk, water use, biodiversity, pollution, etc.

Market prices of olive oil and wage rates were considered either to remain at constant levels or to increase at 2 % per year. The EU policy changes are assumed to lead to subsidy reductions after 2013 of either 2 % per year (moderate) or 4 % per year (strong). Of the eight possible different combinations (with above three factors), four options have been selected and given appropriate names: Stable market (constant prices and moderate subsidy reduction); Bright market (increasing oil prices and moderate subsidy reduction); Doom market (increasing wages and strong subsidy reduction) and the Bleak market scenario (increase of both oil prices and wages, and strong subsidy reduction).

The model was run for all five target areas. Details on the model and its results are presented in Fleskens and de Graaff (2006). Here, the results for the Trás-os-Montes area will be highlighted.

Cross-compliance in the scenarios

Cross-compliance in the model determines whether a farmer receives the full subsidy under the SPS. The amount of the initial SPS payment is based on the production in the reference period (1999-2002), i.e. 223 € ha^{-1} for traditional orchards (SMOPS PT1), 455 € ha^{-1} for semi intensive low input orchards (SMOPS PT2), 645 € ha^{-1} for semi intensive high input orchards (SMOPS PT3, geared towards table olive production), and 182 € ha^{-1} for organic orchards (SMOPS PT5).

A constraint determines the total annual eligibility for the single farm payment. There is a penalty of 5 % for areas not compliant with cross-compliance rules, and additional penalties of 10 % and 5 % for respectively second year and third year non-compliant areas. Any area with a non-compliance history of more than three years is considered not eligible for subsidies under the single farm payment scheme.

In order to qualify for cross-compliance, certain management interventions are required. These are indicated in Table 3. Winter cover management is required in all SMOPS, it is here assumed to require 4 manhours and € 10 more than conventional tillage (Table 2). Terraces occur in different systems, in particular in traditional and semi-intensive high input SMOPS, and because of the steep slopes terraced fields have a relatively high chance of being abandoned. Terrace maintenance requires 10 manhours and € 80 material costs. Farmers with abandoned orchards can still obtain subsidies, as long as they apply pruning and maintain terraces (among others for fire control). This pruning requires 12 manhours and € 7 for material costs.

Table 3. Cross-compliance conditions, additional inputs and estimated environmental effects (extent in brackets) per SMOPS type, as considered in the model.

Smops	Initial subsidy amount	Cross-compliance conditions (environmental effects[1)])			Additional inputs required	
	€ $ha^{-1}yr^{-1}$	Winter cover [2)]	Pruning	Maintenance of terraces	Labour (h $ha^{-1}yr^{-1}$)	Variable costs (€ $ha^{-1}yr^{-1}$)
PT0	-	Yes (-1/0/1)	Yes (0/-0.03/0)	Yes (-2/0/2)*0.4	20	59
PT1	223	Yes (-1/0/1)	No	Yes (-2/0/2)*0.3	7	34
PT2	455	Yes (-1/0/1)	No	Yes (-2/0/2)*0.1	5	18
PT3	645	Yes (-1/0/1)	No	Yes (-2/0/2)*0.3	7	34
PT5	182	Yes (-1/0/1)	No	Yes (-2/0/2)*0.2	6	26
PT9	-	Yes (-1/0/1)	No	No	4	10

Notes:

[1]Environmental effects presented (in brackets after Yes) in the order: reduction of soil loss (t ha^{-1} yr^{-1}); reduction of wildfire risk (burned area fraction); increase of biodiversity index value (dimensionless);

For maintenance of terraces also fraction of area initially under terraces is indicated (multiplication).

[2] The additional inputs for winter cover, above the inputs required for tillage is interpreted concern both additional labour (valued at 5.5 € h^{-1}), materials and herbicide application (7 lt ha^{-1} yr^{-1}).

Results of the scenario studies

1. Effects of scenarios on SMOPS distribution

Based on the different structural features and production costs of the SMOPS the model reallocates the olive orchard area, both through abandonment and by changes towards other SMOPS. These changes in the period 2005-2030 are shown in Tables 4 and 5 for the four scenarios in the Trás-os-Montes (ToM) region in Portugal. In Table 4 it is assumed that a minimum return to labour (equal to local wage rate) is required, and results are shown for a situation without and with the (costs of) cross-compliance obligations. In Table 5 the minimum return to labour constraint is removed.

In all but the Bright market scenario in Table 4, considerable abandonment is projected, in particular in the situation with cross-compliance obligations. And the cross-compliance obligations seem somehow to restrain the move towards more productive systems, e.g. in the Bright market scenario from semi-input low input to intensive systems. In Table 5, without the minimum return to labour constraint, this is less pronounced, but also visible in the move from traditional to organic systems in the Stable and Doom market scenario.

Both tables show that the model predicts a move away from traditional systems: towards semi-intensive low input systems (in bright and bleak scenarios), towards intensive systems (in bright scenario) and towards organic systems (in stable and doom scenarios). The semi-intensive high input system constitutes a special case (table olives), which are either retained (in Stable and Doom scenarios) or abandoned.

The figures in the column on the right indicate that farmers would fulfil the cross-compliance obligations to some extent also after abandonment, in order to remain eligible to subsidies, in particular in the stable market scenario. On the other hand cross-compliance obligations (costs) seem to lead to more abandonment.

Table 5 represents for all but the Bright market scenarios a continuation of less intensive olive production, whereby the return to labour remains below the local wage rate and which constitutes to some extent "hobby farming". It is important to note that the present situation (2005) is also not economically feasible at market wage rates, so that the results in Table 4 may overestimate abandonment rates. Still, in Table 5 abandonment of about 20 – 30 % of olive orchards occurs in all but the bright market scenario. Labour-extensive organic olive production may then become an important production system under these 'hobby-farming conditions'.

In general, a rising olive oil price triggers the intensification process (Bright scenario), while a stable oil price leads to extensive systems (Stable scenario) or abandonment (Doom scenario), depending on the trend of the price of labour (wages).

Table 4. Changes in the Trás-os-Montes SMOPS area **with** minimum return to labour constraint.

Scen./year	Traditional PT1	Semi- low input PT2	Semi- high inp. PT3	Intensive PT9	Organic PT5	Aband PT0	Cross-compl. %
In 2005	59	29	6	0	6	0	Not oblig
			A: **with** cross-compliance obligations				
Stable 2030	12	0	6	1	0	81	81
Bright 2030	1	90	0	9	0	0	84
Doom 2030	0	0	0	0	0	100	23
Bleak 2030	1	1	0	15	0	83	19
			B: **without** cross-compliance obligations				
Stable 2030	11	0	6	9	40	33	-
Bright 2030	0	20	0	80	0	0	-
Doom 2030	1	1	6	5	0	87	-
Bleak 2030	0	66	0	6	0	28	-

Table 5. Changes in the Trás-os-Montes SMOPS area **without** minimum return to labour constraint.

Scen./year	Tradi-tional	Semi-low input	Semi-high inp.	Intensive	Organic	Aband	Cross-compl.
	PT1	PT2	PT3	PT9	PT5	PT0	%
In 2005	59	29	6	0	6	0	Not oblig
A: **with** cross-compliance requirements							
Stable 2030	22	0	6	2	40	30	89
Bright 2030	0	18	0	82	0	0	89
Doom 2030	15	0	6	4	47	28	85
Bleak 2030	0	78	0	0	0	22	86
B: **without** cross-compliance requirements							
Stable 2030	1	0	6	9	60	23	-
Bright 2030	0	19	0	81	0	0	-
Doom 2030	1	0	6	9	60	23	-
Bleak 2030	0	66	0	6	0	28	-

2. Effects of scenarios on environment

Tables 6 and 7 show the effects on income, employment and on several environmental factors, of the four scenarios. These effects strongly relate to the trends in SMOPS area distribution, and a high level of abandonment leads automatically to low levels of income and employment and lower levels of erosion, water use and pollution.

This is most apparent in Table 6, which concerns the situation with the minimum return to labour constraint, as in Table 4. Large scale abandonment under cross-compliance conditions, would bring on the one hand positive environmental effects (less water use and pollution), but would increase the fire risk, and not only because of a lack of pruning. In the Stable market scenario, whereby farmers surprisingly still respect cross compliance, it will also reduce soil erosion.

When there would be no cross-compliance obligations, the minimum return to labour constraint appears to be only binding in the Doom market scenario (see Table 4). Therefore the figures under B in the two tables 6 and 7 are quite similar for the three other scenarios.

Table 6. Effects of scenarios on environmental factors in the Trás-os-Montes, **with** minimum return to labour constraint.

Scen./year	Income € $ha^{-1}yr^{-1}$	Labour h yr^{-1}	Erosion MT $ha^{-1}yr^{-1}$	Fire risk Burnt (%)yr^{-1}	Water use m^3 $ha^{-1}yr^{-1}$	Pollution index val
In 2005	307	1329	3.1	0.09	90	2.6
A: **with** cross-compliance obligations						
Stable 2030	248	494	0.9	0.16	104	0.5
Bright 2030	820	1310	3.8	0.07	184	5.1
Doom 2030	52	53	1.6	0.19	3	0.0
Bleak 2030	272	341	2.0	0.17	293	0.8
B: **without** cross-compliance obligations						
Stable 2030	393	867	1.9	0.11	275	4.6
Bright 2030	1047	1870	3.4	0.03	1598	5.1
Doom 2030	256	323	2.2	0.18	192	0.7
Bleak 2030	732	908	4.1	0.11	120	3.7

It should be realised that the relatively large increases in income in the Bright market scenario are not only due to higher production (intensive system), but also to the higher prices and subsidies and lower labour costs in that scenario.

The calculations have been made for the average situation, whereby only part of the unit area is terraced and requires maintenance costs. A farmer who has all of his olive land under terraces will incur much higher costs for cross-compliance: a total of € 167 ha^{-1} (at market wage rate), which is quite close to the amount of subsidy he could get for traditional SMOPS (€ 223 ha^{-1}). If he abandons the orchard and would still like to receive the subsidy, he would also have to undertake the pruning at € 73, and then the costs will exceed the subsidy.

Table 7. Effects of scenarios on environmental factors in the Trás-os-Montes, **without** minimum return to labour constraint.

Scen./year	Income € $ha^{-1}yr^{-1}$	Labour h yr^{-1}	Erosion MT $ha^{-1}yr^{-1}$	Fire risk Burnt (%)yr^{-1}	Water use m^3 $ha^{-1}yr^{-1}$	Pollution index val
In 2005	307	1329	3.1	0.09	90	2.6
A: **with** cross-compliance obligations						
Stable 2030	324	922	0.6	0.11	121	4.2
Bright 2030	1015	1922	2.5	0.03	1632	5.1
Doom 2030	260	932	0.6	0.11	165	5.0
Bleak 2030	690	985	3.3	0.10	0	4.0
B: **without** cross-compliance obligations						
Stable 2030	378	920	1.6	0.10	275	6.5
Bright 2030	1050	1884	3.4	0.03	1629	5.1
Doom 2030	310	920	1.6	0.10	275	6.5
Bleak 2030	732	908	4.1	0.11	120	3.7

And these calculations do not yet include the costs of other cross-compliance obligations, e.g. with regard to avoiding degradation of habitats.

The probability of non-compliance is higher for less productive orchards. As the subsidies under the SPS are determined by production in the reference period (1999-2002), subsidies are low for originally traditional and extensive types of SMOPS (PT1 and PT5) and high for semi-intensive orchards (PT2 and PT3).

Conclusions

The past subsidy regime, with payments based on amounts of olive oil produced, has led to intensification of production and adverse environmental effects, in particular soil erosion. Under that regime obligatory cross-compliance could have been an important policy instrument. Under the new subsidy regime with fixed payments based on previous performance, the incentives to intensify at high environmental costs have decreased and cross-compliance is less urgent.

Cross compliance is principally aimed at higher environmental sustainability. However, the scenario analysis shows that SMOPS that presently seem to be environmental friendly (traditional, organic and abandoned ones) have to incur the highest costs (Table 3), but are the ones least likely to respect the cross compliance obligations. The analysis also shows that these obligations may actually lead to higher abandonment, and that they some how restrain the move towards more intensive orchard systems.

Traditional farms on steep land have already negative financial returns and can only continue their olive production, when they accept lower opportunity costs of their labour. They had in 1999-2002 low production levels, and under the new subsidy regime (Single Payment Scheme) can not obtain more subsidy anymore through better management. They will therefore not be very eager to undertake cross-compliance measures, and may take the chance that their subsidy will be reduced in the first year by some 5 %. In the case that they will be caught for non-compliance, they could still start applying the measures in the next year. The chance to be caught is anyhow not very high, because the number of EU controllers is rather limited.

It is therefore a pity that the producing countries have decided to go for more or less complete decoupling, eliminating the options for national envelopes to cater for environmental and social improvements in the olive sector. The latter idea was not worked out in sufficient clear details to convince farmers and policy-makers of their eventual advantages. Besides, in Portugal with predominant traditional orchards, the financial transfer from high- to low-productive orchards could not be very significant.

It will be important to increase now the amount of support under the Agri-Environmental Measures (AEM), in particular for the traditional, semi-intensive low input and organic systems, in order to keep them environmentally friendly.

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Soil protection in sloping Mediterranean agri-environments: The case of the Priorat vineyard region (NE Spain)

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Abstract

New market opportunities and EU Common Agricultural Policies are encouraging accelerated land use and landscape changes in agricultural areas in mountain environments of the Mediterranean region. New farming systems based on the construction of bench terraces by means of heavy machinery (without a previous engineering design) are being implemented. An example of this situation is the Priorat region (Catalonia, NE Spain), where vineyards have been cultivated since the XII century in hillslopes by man and animal labour. Since the beginning of the 1990s the region is experimenting important changes around new wine market opportunities, which are lately encouraged by EU policy for vineyards' conversion and restructuring. This policy subsidizes up to 50% of the cost of the actions. In this paper, we tackle several aspects of the changes that modern farming systems are causing in the region: a) the quantification of land use changes after the coming into practice of the EU vineyard restructuring policy, and b) the assessment of terrain morphology changes due to land terracing and some derived geomorphological effects. References to terrace design criteria and studies about effects on changes of soil properties and intra-field variability induced by the land movements are also given. The results show high terracing rates (22.6 to 36.1 ha year^{-1}) in the study period (1998 – 2006), accompanied by huge land movements (cutting rate of about 5,475 m^3 ha^{-1}). Bad design of terraces derives in collapse of benches and borders, affecting about 3.5% of the surface of the new plantations. Land movements also affect soil properties and induce high intra-field variability, which is maintained along the years. These effects question the application and/or convenience of the EU Common Agricultural Policy for vineyards' restructuring in Mediterranean mountain environments. The case study also presents two exercises dedicated a) to review the criteria of terrace design and b) to compute the earth movements involved in terrace construction.

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Introduction

Agricultural areas of Europe have undergone major changes since the advent of mechanization in the 1950s and the establishment of the EU Common Agricultural Policy (Tanrivermis, 2003; Borselli et al., 2006; Hooke, 2006). This has either promoted the intensification of agriculture or the abandonment of crops in traditional agricultural areas. Clear examples of abandonment and marginalization of agricultural land uses are most of the Mediterranean mountain environments traditionally devoted to subsistence farming (Caraveli, 2000; Busch, 2006). This situation is however changing at present because of new market opportunities and marketing techniques, and the implementation of conversion and restructuring policies, which are encouraging accelerated land use changes. In particular, these subsidies have favoured the extension and conversion of traditional crops such as olives and vines, leading to a replacement of traditional low-intensity production systems by farming systems based on high technology and mechanization (Martínez-Casasnovas and Sánchez-Bosch, 2000; Allen et al., 2006).

The intensification of agriculture in mountain environments requires land levelling and terracing (Zalidis et al., 2002; Borselli et al., 2006). This reduces some of the morphology limitations of hillslopes for agriculture, favours the mechanization of tillage operations and reduces labour. However, levelling and terracing are entailing fast and irreversible changes in soil properties and land morphology of still unknown consequences. In this respect, there are some reference works that have reported repercussions of land levelling operations (e.g. Martínez-Casasnovas and Sánchez-Bosch, 2000; Lundekvam et al., 2003; Faulkner et al., 2003; Jiménez-Delgado et al., 2004; Borselli et al., 2006;). One of the best examples of extensive land levelling, promoted by agricultural policies, is Norway (Lundekvam et al., 2003), where land levelling was introduced during the 70s to increase grain production in lowland areas and animal production in mountainous areas. Former ravine landscapes changed into arable land. As a consequence, soil erosion increased, which in the early 1990s conduced to the introduction of several kinds of subsidies to encourage more sustainable agriculture (Lundekvam et al., 2003). In other countries such as Hungary, Italy, Portugal or Spain, the objective of land levelling and terracing has been the mechanization of vineyards or olive groves in sloping terrain (Jiménez-Delgado et al., 2004; Borselli et al., 2006). Some negative effects after those operations have been reported: e.g. the increase of soil loss from 10.8 to 25% of the land in the Penedès vineyard region (NE Spain) (Martínez-Casasnovas and Sánchez-Bosch, 2000), the increase of the annual soil loss by 26.5% on average in levelled vineyard fields (Jiménez-Delgado et al., 2004), or the irregularity of soil depth and alteration of natural soil drainage and soil hydrological properties (Ramos and Martínez-Casasnovas, 2006). In other cases, if not accompanied by preventative measures, the modification of slope morphology by levelling can destabilize the equilibrium along the slope (Torri et al., 2002), deriving in the substitution of a rill network by gullies or the increase of shallow mass movements (Borselli et al., 2006).

Land levelling or terracing are poorly regulated either by specific or environmental laws. Because of that, the design and implementation of those operations usually rely on the field owner or on the person in charge of the machinery. Then, as no technical guidance is available, procedures can be decided by incompetent persons (Borselli et al., 2006). For example in Spain, the modification 6/2001 of the Environmental Impact Law (RD 1302/1986, 28/06/86) introduces that transformation of non cultivated areas with natural vegetation in sloping terrain must be accompanied by an impact assessment study, including all the necessary/required measures to preserve the topsoil. However, owners can transform up to 50 ha without an environmental impact assessment declaration. Hence, to a large extent, levelling or terracing escape any control.

In Mediterranean Europe, several clear examples that illustrate the main effects of environmental and landscape impacts of land levelling and/or terracing can be quoted (Drescher, 1995; Jiménez-Delgado et al., 2004; Borselli et al., 2006; Cots-Folch et al., 2006; Hooke, 2006). Those are mainly related to the expansion of vineyards, which at present is being stimulated by the EU Common Agricultural Policy. One of those examples is the Priorat region (Catalonia, NE Spain) (Figure 1). This is a traditional area for wine production where vineyards have been cultivated in hillslopes with small stone wall terraces. However, from the late 1980s there is a boom of viticulture, based on a new terracing system, which allows mechanization of labours but causing high environmental and landscape impacts. In this paper, we approach several aspects of the changes that this modern farming system is causing in the region: a) the quantification of land use changes during the period 1998 – 2006, after the introduction of the EU vineyard conversion and restructuring policy, and b) the assessment of terrain morphology changes due to land terracing and derived geomorphological risks. The effects and convenience of the EU Common Agricultural Policy for vineyards' restructuring in Mediterranean mountain environments is finally discussed in relation to the sustainability of the modern vineyard farming systems.

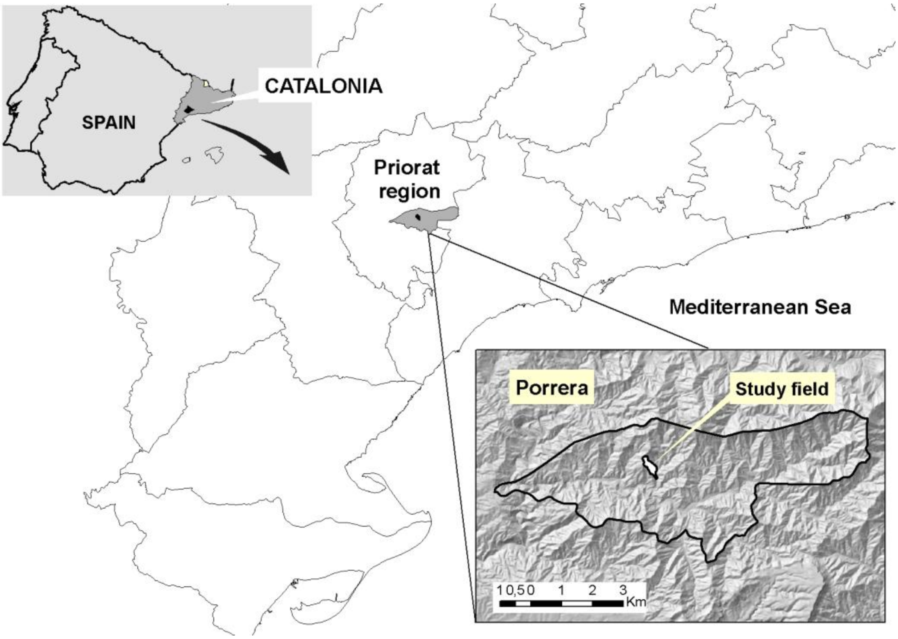

***Figure 1**: Location of the study area.*

Material and methods

1. Study area

a. Location and general physiographic characteristics

The Priorat region (Catalonia, NE Spain) (Figure 1) covers about 180 km^2 and is characterized by high slope degree (24.2º on average) and an elevation range comprised between 80 - 1140 m (a.s.l.). The climate is Mediterranean with continental influence. The average annual temperature is 15ºC, ranging from 6º to 23ºC. Average rainfall is about 550 mm, concentrated in spring and autumn. The region is located between two of the major geomorphologic units of the north-eastern part of the Iberian Peninsula: the Ebro Basin to the north and the Catalan Mediterranean System to the south. The Priorat mountain chain is an outcrop of Palaeozoic, mainly formed by clastic sediments from the Carboniferous consisting of rhythmic sequences of sandstones, schists and calcareous material (Pla et al., 2004). Based on Soil Taxonomy (Soil Survey Staff, 1999), soils are classified as Lithic Xerorthents, developed on schist (locally named "llicorell"), which cause high stoniness on topsoils (usually

>70%). This makes that soils have high infiltration capacity and low water retention capacity (Pla et al., 2004). Soil characteristics and climate conditions limit crop production, which in the case of grapes is about 1200 to 6000 kg ha^{-1}. The dominant natural vegetation are the "garrigues", a poorer version of maquis, composed primarily of leathery, broad-leaved evergreen shrubs that appear after land abandonment. Tree species, that are prominent in the area, include *Pinus halepensis* and *Quercus ilex*.

At present, vineyards occupy about 15% of the land, being the only relevant cultivated crop in the region. Historically, the maximum expansion of vineyards was in the late 18th century and early 19th century, occupying up to 74% of the land (Morera, 1915). This was favoured at time by a high international demand for wine and liquor and by the appearance of the phyloxera (*Phyloxera vastatrix*) in France, which supposed the death of the French vineyards.

The study area of the present research is the municipality of Porrera, considered representative for the region's farming systems and transformations that have been taken place since the late 1980s. It has an extension of 2,896 ha, which represents 16.5% of the Designation of Origin Priorat area.

i. Traditional versus modern farming system

At present, two main types of farming systems coexist in the study area: traditional and modern farming systems. The traditional farming system is based on hillslope cultivation (usually with degrees higher than 50%) with or without slope stone terraces. The terraces have the objective to reduce soil and water losses and to facilitate cultivation and the transit of man or animals to perform crop operations (Figure 2). The implementation of this terracing system does not produce significant terrain morphology transformation, since it does not involve the building of level or nearly level benches, for which a large amount of cutting, filling and power is required.

Figure 2*: Traditional hillslope vineyard with slope stone walls in the Priorat region.*

During the first half of the 20th century there was depopulation of the region caused by a crisis in the agricultural sector and a deintensification and abandonment of agricultural land, also quoted by other authors in different Mediterranean mountain environments (Douglas et al., 1994, 1996; Lasanta et al., 2001). In the Priorat, this situation was partially overcome during the late 1980s, when a small group of producers introduced new vinification and marketing techniques. It pushed local wines towards the top of the international markets, which attracted investors to transform old plantations or abandoned lands in new vineyard plantations. The modern farming system is based on the use of machinery (small tractors). This requires land terracing, that is achieved by mean of bulldozers and retroexcavators. These bench terraces, with unprotected borders, require important cut and fill, resulting in the alteration of original soils and natural drainage ways, and in landslides that produce important damage to vines, irrigation systems and training systems (Figure 3).

Figure 3*: Modern mechanized vineyard plantation in the Priorat region based on linked bench terraces and support irrigation. The borders of the terraces are unprotected.*

b. Land use change analysis

Land uses in the Priorat region were characterized for the period 1998-2003, when major and accelerated changes occurred. For that, detailed land use maps were derived from 1:5,000 orthophotos of 1998 (Cartographic Institute of Catalonia) and a specific flight carried out for this research in 2003 (approximate scale of 1:10,000). Land use maps were created by photo-interpretation. The delineation of the cartographic units was done on 1:5,000 orthophotos. The 2003 orthophoto was previously generated from the ortorectification of aerial photos. For the 2003 situation, the land use delineations were checked in the field in sample areas, in order to validate the class interpreted from the aerial photos with the one existing in reality. This process also served to establish the photo-interpretation elements that were used to produce the land use map of 1998. The following land use classes were considered: dense forest, open forest, shrub land, rainfed fruit trees, abandoned fruit rainfed trees, traditional vineyard, new terraced vineyard, urban area, river bed and other minor uses.

The software ArcGIS 9.0 was used to delineate the land use maps and to analyze the changes. The latter were determined by means of cartographic comparison of the land use maps.

In addition to this analysis, data about the vineyard plantations created in the campaigns 2000/01 to 2005/06 in the municipality of Porrera (Priorat) was obtained from the Department of Agriculture of the Catalan Government.

c. Terrain morphology changes and derived geomorphologic effects

Terrain morphology changes due to land terracing and derived geomorphologic effects were determined in a sample field of the municipality of Porrera of 14.3 ha (see study field in Figure 1). The elevation ranges from 290 to 478 m, with an average slope degree of 49.6%. Land terracing was carried out between 2000 – 2003 with the aid of retroexcavators and bulldozers. The terraces are of linked bench type. Their construction was based on the expertise of the retroexcavator driver, allowing two vine rows per bench.

The assessment of terrain morphology changes was based on the relief reconstruction at a date previous to the construction of terraces (1986) and one after (2003). For that, detailed digital elevation models were built from interpolation of height data (2 m spaced contours and spot heights). These data were produced by a digital photogrammetric restitution process, using the Digital Image Analytical Plotter (DIAP) software. For the 1986 situation, 1:18,000 aerial photos (Cartographic Institute of Catalonia) were used. The geometric transformation produced a root mean square error of ±5 mm in X, Y and Z (elevation). The data were complemented by hard slope breaks that shape the terraces and other significant terrain inflections. Triangulated Irregular Networks (TINs) were created using the capabilities of the 3D Analyst extension of ArcGIS 9.0, which were afterwards used to interpolate the height for the center-cell position of all cells in regular output grids. The horizontal resolution given to the grids was 1 m and the vertical resolution was 0.1 m. From these data, the quantification and location of terrain morphology changes was based on Equation 1.

Equation 1 $$V = ([DEM2003] - [DEM1986]) \cdot GR^2$$

Where: V = Volumetric difference (m^3),

[DEM2003] = Digital Elevation Model of the year 2003 (m),

[DEM1986] = Digital Elevation Model of the year 1986 (m),

GR = Horizontal grid resolution (m) (1 m).

Three years after the construction of the terrace system a survey was carried out in the same field to map the collapse of terrace borders and damages in vines and infrastructures. The terrace design parameters (vertical and horizontal intervals, riser slope, terrain slope and bench width) were analysed for 23 terraces across the field (Fig. 2). A Geodimeter 422 total station, with

±0.01 m resolution, was used to acquire the required data for the analysis. The XYZ data of the points acquired in the field allowed the assessment of terrace dimensions and the slope of the risers. In addition, another survey to locate and measure the soil and mass movements which occurred in the study field was carried out. The location of the soil and mass movements was determined by a GPS Trimble GeoExplorer XT with differential correction, with a resolution of less than 1 m. The dimensions of mass movements (area affected and maximum and average soil depth removed), as well as the infrastructures and plants damaged by the movements, were evaluated in the field.

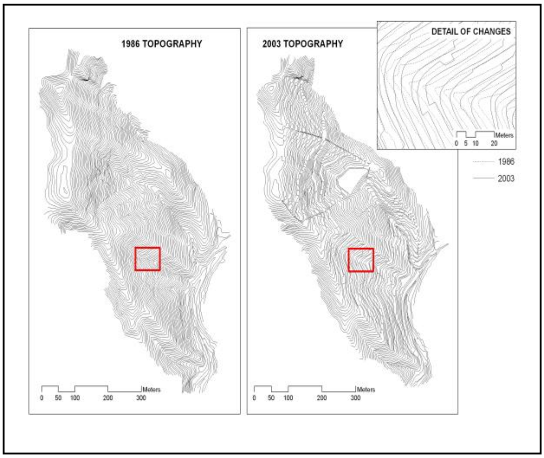

***Figure 4**: Comparison of pre-terracing topography (1986 situation) and post-terracing topography (2003 situation). Contour interval is 2m in both representations.*

Results

1. Land use change analysis

The analysis of the land use maps of the municipality of Porrera in 1998 and in 2003 reveals that the main land uses are those corresponding to natural vegetation (dense forest, open forest and shrub land): 76.3% in 1998 and 72.8% in 2003 (Table 1 and Figure 5). This contrasts with the figure of 74% of the land occupied by vineyards at the end of the 19th century (1894), as reported by Morera (1915), and shows up the degree of the abandonment suffered in this rural area during the 20th century. This land abandonment in the Priorat is similar to other Mediterranean mountain environments which were intensively used in the past for agriculture (Gallart et al., 1994; MacDonal et al., 2000; Dunjó et al., 2003).

Table 1. Land uses in the municipality of Porrera (Priorat) for years 1998 and 2003.

Land use class	1998 (ha)	1998 (%)	2003 (ha)	2003 (%)
Dense forest (>40% vegetation cover)	824.6	28.5	875.7	30.2
Open forest (5 – 40 % vegetation cover)	924.0	31.9	854.2	29.5
Shrub land	459.5	15.9	378.5	13.1
Rainfed fruit trees	232.9	8.0	150.6	5.2
Abandoned fruit rainfed trees	185.9	6.4	174.0	6.0
Traditional vineyard	95.0	3.3	106.8	3.7
Terraced vineyard	111.0	3.8	291.3	10.1
Urban area	24.0	0.8	24.9	0.9
River bed	35.6	1.2	36.9	1.3

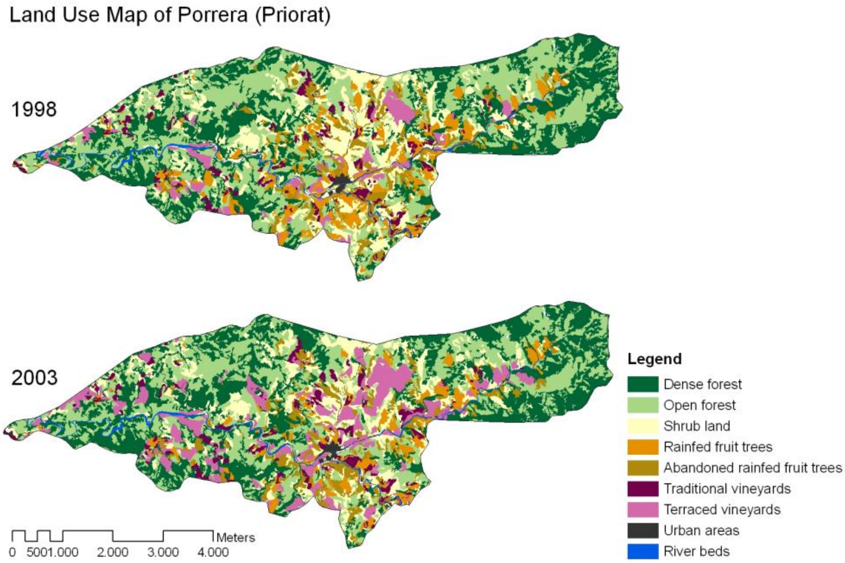

***Figure 5**: Land use maps of Porrera (Priorat): 1998 and 2003.*

Regarding vineyard changes, Table 1 shows a slight increase of the traditional vineyard class (3.3% in 1998 and 3.7% in 2003), and a very important increase of the terraced vineyard class: 3.8% in 1998 and 10.1% in 2003. The average transformation rate (terracing for new vineyard plantations) in this municipality is 36.1 ha $year^{-1}$, which is considered as very high taking into account the physiographic limitations of the terrain (schists rocks, high slope degree and limited accessibility). New vineyard plantations appeared mainly as conversion of old rainfed tree plantations (almonds and hazelnuts) and shrub land (old abandoned fields) (Table 1). The same trend is observed in the whole Priorat region, in which vineyard land has increased from 876 ha in 2000 to 1591 ha in 2003(data from the Department of Agriculture of the Catalan Government), which supposes a terracing rate of 0.013 ha ha^{-1} $year^{-1}$, similar to the 0.012 ha ha^{-1} $year^{-1}$ obtained for the municipality of Porrera.

If we compare the computed transformation rate from other uses to terraced vineyards from the land use change analysis (1998 to 2003) with the computed from the new vineyard plantations registered yearly in the data base of the Department of Agriculture of the Catalan Government (Table 2), some differences can be appreciated (36.1 ha $year^{-1}$ versus 22.6 ha $year^{-1}$). These differences are due to the different analyzed periods but also to a deceleration in planting new vineyards because of an excess of wine supply in relation to the demand of Priorat wines. This deceleration is higher in the last campaigns, since the total grape yield in the Priorat increases according with the starting of production of 3-4 years old plantations (Table 2).

If any of the computed average rates were maintained, and if the conversion is not made at the expense of traditional vineyards, the estimated surface of vineyard land in 2010 for Porrera would be 556.3 ha (19.2% of the land) in the case of the lowest rate or 650.8 ha (22.5% of the land) in the case of the highest rate. Those figures are still far lower than the area occupied by vineyards in the late 18th century and early 19th century (74% of the land) (Morera, 1915), or at the beginning of the 20th century (66.4% of the land in 1900) (Iglèsies, 1975).

Regarding traditional vineyard plantations, their slight increase in area is explained by the better quality of wines produced from old vineyards (50 – 80 years old). This leads to the recovery of these old and almost abandoned vineyards, which are often situated on hillslopes.

Table 2. Surface of new vineyard plantations in the municipality of Porrera (Priorat).

Campaign	ha
2000/01	33.61
2001/02	28.93
2002/03	19.55
2003/04	26.73
2004/05	13.46
2005/06	13.65
Total	135.94
Average	22.66

Source: Department of Agriculture, Catalan Government.

2. Terrain morphology changes and derived geomorphologic effects

Land terracing for new vineyard plantations in the Priorat region is carried out at present with the aid of heavy machinery for earth-moving (bulldozers and excavators), which implies huge cutting and filling per unit area (Figure 6). The results of the multitemporal DEM analysis between 1986 (before terracing) and 2003 (after terracing) to assess terrain morphology changes are detailed in Figure 7 and summarized in Table 3. These show that, in Porrera, cutting accounted for 5,475 m^3 ha^{-1}. The balance between cutting and filling is negative, with a value of 3,026 m^3 ha^{-1}. This is attributed to a higher compression of the materials by the heavy machinery during the process of terrace construction. This compression is favoured by rock crushing, which is performed before the plantation to facilitate mechanical labours and to increase water retention (Cots-Folch et al., 2004; Abreu, 2005).

***Figure 6**: Example of bench terraces constructed at present with heavy machinery in the Priorat region.*

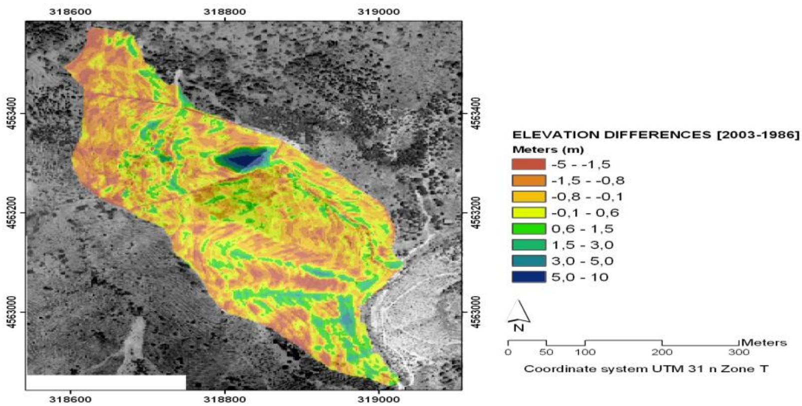

***Figure 7**: Elevation differences between 1986 and 2003 in the sample field study area computed from the subtraction of detailed digital elevation models.*

Table 3. Summary of the multitemporal DEM analysis [2003 – 1986].

Land moveme nt type	Affected area (ha)	Mean elevation difference (m)	Elevation difference range (m)	Volume (m^3)*	Volume (m^3 ha^{-1})*
Cutting	8.5	-0.91	-5.01 - -0.1	-77,746±7,400	-5475±521
Filling	4.3	0.80	0.1 – 9.62	34,778±3,760	2449±264
Without significant changes	1.2	-0.002	-0.1 – 0.1	-19.7±1,000	1.39±70

*The figure after the symbol ± indicates the deviation at 95% confidence interval.

Taking into account the original bulk density of the soils, 1.74 Mg m^{-3}, land movements in the study area accounted for 9,526 Mg ha^{-1}. In comparison to other natural processes acting for soil redistribution and terrain morphology changes, as for example soil erosion processes or mass movements, the above mentioned land movement rate fully overcomes the figures due to the first (soil erosion processes), even those measured in large gullies in a yearly scale: e.g. 1,550 to 2,480 Mg ha^{-1} yr^{-1} (DeRose et al., 1998) or 1,322 Mg ha^{-1} yr^{-1} (Martínez-Casasnovas, 2003). This confirms land terracing as an induced geomorphic processes which is able to reshape terrain morphology in very short time scale, leaving a mark that will be difficult to erase in the short or middle term.

The modern terracing system in the Priorat is producing important topographical land transformation that entails different type of problems as burial of original soils and change of soil physical and chemical properties (Cots-Folch et al., 2004), similarly to other research areas (Querejeta et al., 2000; Brierley and Stankoviansky, 2003). In addition, mass movements due to the inconsistency of the new slopes, as also stated by Shrestha et al. (2004), are frequent in the analyzed terraced field (Figure 8). The survey carried out in this experimental field identified 73 mass movements of different magnitude along the slope. The affected surface was 4950 m^2 (3.5% of the field surface). Seventy five percent of that area was located in terrace borders in the lower third of the slope, and 20% in the upper third of the slope. The rest occurred in the middle part of the slope. This distribution is most probably explained by the way the terraces are constructed, starting from the top of the slope (upper part of the slope or water divide) to the bottom (lower part of the slope). This leads to unconsolidated material from cutting operations being accumulated in the lower part of the slope.

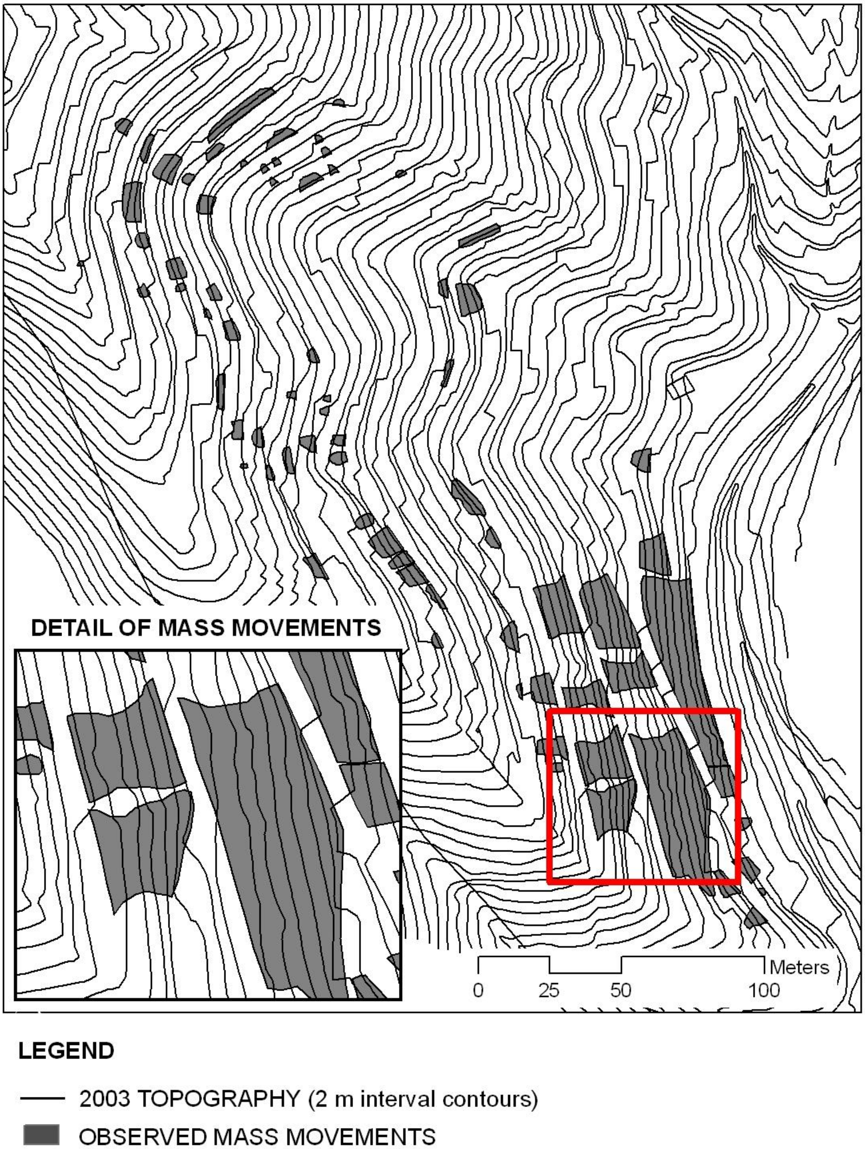

***Figure 8**: Location of mass movements in terraces of the experimental field. Background: 2003 orthophoto.*

Mass movements caused damages on the plants and field infrastructures (Figure 9). In the experimental field, 319 plants out of 18,500 (1.7%) were affected, with 97.5% of them located in the lower third of the slope, corresponding to 6.9% of the plants in the lower slope. In addition, irrigation tubes and training structures were also damaged in the lower third of the slope. Some of the benches were blocked, obstructing the pass of the machinery in those terraces. Due to the high slope degree and difficulties for retroexcavators access, restoration of the terraces has not been possible, and these zones have been abandoned.

Figure 9*: Mass movement produced by the collapse of a border in an area with excessive filling of materials and high slope degree. The foot slope vine row has been buried by the moved materials.*

Discussion

The Council Regulation EC No 1227/2000 of 31st May 2000 established the vineyard restructuring and conversion plans with the objective to adapt the production to the market demand. For the study area, Table 4 shows the restructuring actions and maximum subsidy applied in Catalonia (Order of the Catalonian Department of Agriculture 42/2003, 30/01/2003), which will be used to discuss the results on landscape effects due to land terracing for new vineyard plantations.

Table 4. Maximum subsidy applied in Catalonia (Spain) for vineyard restructuring actions (Order of the Catalonian Department of Agriculture 42/2003, 30/01/2003).

Action	Maximum subsidy (€ ha^{-1})
Uprooting	421
Plantation	
Soil preparation	962
Plant (4500 plants/ha)	9315
Other plantation costs	240
Cost of cultivation	1052
Training	2705
Change from non-trained vines to trained vines	2849
Fence	4958
Horizontal lifted training	1772
Canary conduction system	8564
Soil disinfection	2104
Stone clearing	391
Land levelling	601
Land terracing	18752
Soil reposition	4207

Table 4 (continued)	
Wind walls	8414
Protection against rabbits	1202
Regrafting	
Graft (unit)	0.60
Other regrafting costs	1202
Fertilization	–
Pesticides	–
Irrigation	–

The vineyard restructuring policy has encouraged wine producers in the Priorat to transform traditional crops into new mechanised and more profitable vineyards. This is demonstrated by the comparison of transformation rates before and after the coming into operation of the plans. In this respect, and although terraced vineyards were already introduced in the Priorat after the market boom at the end of the beginning of the 1990s, with transformation rates of 7.5 ha year^{-1} (Cots-Folch et al., 2006), the actual transformation rates have been multiplied by 3.0 or 4.8 (depending on the time period considered). This scenario is changing, however, since a deceleration of the intensification process is observed (Table 2) and the vineyards' restructuring policy is coming to the end (2008). This deceleration, which is mainly linked to a decrease of the wine market prices, could also derive in a new land abandonment process, as in other documented cases (Gallart et al., 1994), producing an increase of soil erosion due to a progressive degradation of the terraces and related infrastructures.

According to data provided by the Regulating Council of the Priorat Qualified Designation of Origin, the average cost of land terracing is about 10,818 € ha^{-1}. This figure represents 34% of the total costs to start a new plantation, and it is similar to other plantation costs (soil preparation, plants and cost of cultivation). The maximum subsidy for land terracing operations is 18,752 € ha^{-1} (Table 4), that represents 26.9% of the total maximum subsidies offered for the creation of a new vineyard plantation. Together with the maximum subsidy assigned to levelling (601 € ha^{-1}), these operations account for 27.5% of the subsidies, which gives an idea of the importance assigned by the EU CAP to land movement in relation to other conversion measures.

Conclusions

Intensification of vineyards in some mountain areas of the Mediterranean region is being encouraged by EU Common Agricultural Policies. This intensification is not based on traditional farming systems but on new ones that imply the construction of bench terraces by means of heavy machinery. Hillslope terracing causes huge displacement of materials (5,475±521 m^3 ha^{-1}) and important terrain morphology transformation. In some cases, bad designed terracing leads to problems such as the collapse of terraces or the damage in vines and infrastructures. In the present case study this has been observed in 3.5% of the surface of the experimental terraced field (14.2 ha), in which 73 mass movements were measured. This could be reduced if engineering projects were demanded with experience in correct terrace construction, and monitored by the corresponding Administration in charge of the subsidy proceeding control.

Land terracing is the most subsidized measure by the EU Council Regulation policy for vineyards' restructuring, accounting for 26.9% of the total maximum subsidies offered for the creation of a new vineyard plantation. This is actuating as a motor that is transforming the mountain environment of the Priorat region, with an average rate of 22.6 ha $year^{-1}$ after the coming into operation of the policy (according to data of the Department of Agriculture, Catalan Government). This fast opportunity land transformation is at present deriving in an excess of wine supply from this qualified region that can lead to other consequences in the medium term, such as the abandonment of non-profitable terraced plantations.

The documented effects on terrain morphology, geomorphological risks and the probable negative consequences of modern vineyard plantations (without required prior designs and by means of heavy machinery) in the medium term, question the effectivity of application of the regulation policy for vineyards' restructuring in mountain environments of the Mediterranean area.

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Exercise 1: Terrace design in sloping areas for vineyard plantation (The Priorat vineyard region, NE Spain)

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Abstract

This exercise provides the methodology to be applied for terrace design in sloping areas. This methodology is applied to the study case of the vineyard area of Priorat, located in the NE Spain, where vineyards have been planted for centuries in steep slopes and recently new terrace systems are being applying.

Terraces

Terraces are earth embankments constructed across the slope to intercept surface runoff and convey it to a stable outlet at a non-erosive velocity, and to shorten slope length. Terraces can be classified into three types: Diversion, retention, bench terraces and Fanya juu terraces.

Diversion terraces are used to intercept runoff and channel it across the slope to a suitable outlet. There are different types of diversion terraces (also named

Channel terraces; Hillslope ditches; Broad or narrow based terraces; Cut off channels

Magnum type: formed by taking soil from both side of embakment

Nichols type: formed by taking soil form upslope side of embakment

Broad-based type: bank channel width 15m

Narrow-base type: bank channel width of 3-4 m

Retention terraces: level terraces (used to conserve or storage water in the hillside

Bench terraces: alternating shelves and risers used to cultivate steep slopes

Fanya Juu: narrow shelves constructed by digging a ditch on the contour and throwing the oil on the upslope side to form a bank

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Diversion Terraces design

Terraces design implies to define the length and capacity and the spacing between terraces. Different approaches may be followed:

- Using empirical equations, based rainfall characteristics, soil erodibility, soil depth and slope
- theoretical approach:
- based on critical slope length at which flow overcome erosive
- (use of the USLE and soil loss tolerance)

a. Terrace length

Terrace lengths are affected by different factors:

- size and shape of the field
- outlet possibilities
- rate of runoff (affected by rainfall and soil infiltration channel capacity)

The number of outlets should be the minimum consistent with good layout and design. Extremely long grade terraces are to be avoided; however, long lengths may be reduce in some terraces by dividing the flow midway in the terrace length and draining the runoff to outlets at both ends of the terrace

The length should be such that erosive velocities and large cross sections are not required. The maximum lengths are summarise in the table 1 (According to Hudon, 1981)

Table 1. Criteria for terrace length design

Maximum length	Normal	250m (sandy soils)
		400m (clay soils)
Maximum slope	First 100m	1:1000
	Second 100 m	1:500
	Third 100 m	1:330
	Fourth 100 m	1:250
	Constant slope	**1:250**
Terrain slope	Absorption terraces	Slope <4,5º
	Drainage terraces	**Slope < 7º**
	Bench terraces	**Slope de 7 a 40º**

Channel terraces design

a. Empirical approach

For the empirical approach we have to estimate the horizontal and vertical distance between terraces as follow accordingly different criteria found in the literature applied in different places:

b. Horizontal distance

The relationship between horizontal and vertical interval is given by the expression:

$$HI = \left(\frac{VI * 100}{S} \right)$$

where HI = Horizontal interval (m); VI* = Vertical interval (m - based on numerous empirical formulae from different geographical locations - see table 2); S = Slope (%)

c. Vertical interval

Table 2. Empirical formula used for channel terrace design

Place	Autor	formulae	observations
USA	USSCS	VI (m) = (a S + b).0.3048	VI=vertical interval between terraces;
			a is a function of rainfall characteristics
			(varies between 0.3 [less erosive] and 0.6 [more erosive]
			b is a function of soil erodibility
			(varies between 1 [less erodible] and 2 [more erodible])
Kenya	Kenyan SCS	VI (m) = 0.3 (S + 2)/4	VI= vertical interval between terraces.
			S = Slope (%);
Zimbabwe	SCS	VI (m) =(S + f)/2	S = slope (%)
			f is a function of the soil erodibility (varies between 3 and 6)

d. Theoretical approach

The theoretical approach is based on the evaluation of the critical slope length at which flow overcome erosive, which may be calculated by the expression:

$$L = \frac{v^{5/2} n^{3/2}}{(R-i)\sin^{3/4}\theta \cos\theta}$$

where L = critical slope length at which runoff becomes erosive; v = maximum permissible velocity; n = Mannings roughness coefficient; R = rainfall intensity (m/h); i = infiltration capacity (m/h); θ = slope (degrees)

and the vertical interval between terraces is:

$$VI = L\tan\theta$$

Bench terraces design

For the design of bench terraces, different empirical formulae have been proposed around the word. Some of them are summarised in Table 3.

Table 3. Empirical equation for bench terrace design

Place	author	formulae	observations
Algeria/ Morocco	Bensalem (1977)		S=slope of terrain (%)
		VI = (260.S)-0.3	Slopes of 10-25%
		VI = (64.S)-0.5	slopes over 25%
India	Lakshmipath & Narayanswamy (1956)	VI= 2(D-0.15)	D=depth of productive soil
Ethipoia	Hunri (1986)	VI=2.5*D	D = soil depth
Taiwan/ Jamaica	Sheng (1988)	$VI = \frac{Wb.S + (0.1.S - U)}{100 - S.U}$	U= slope of the riser. (U=HI/VI) Usually: 1-0.75)
China	Fang et al. (1981)	$VI = \frac{Wb}{\cos S - \cos\beta}$	B = angle of slope of the riser (70-75º)

Taiwan	Chan (1981)	$VI = \frac{S.Wb}{100 - S.U}$	Sloping bench terraces U= slope of the riser S=slope of the terrain Wb=width of the shelf

Waterways design

The designs are based on the principles of open-channels hydraulics. It is an application of the Manning equation of flow velocity. The cross- section of the waterway could be triangular, trapezoidal and parabolic. However, triangular sections are not recommended because of the risk of scour at the lowest point, and with time trapezoidal section tend to be parabolic.

The waterways in soil conservation plans are normally designed to convey the peak runoff expected with a 10-year return period without causing scour or fill. The design is based on the conditions expected to prevail 2 years after installation. Design is based on the concept pf a maximum allowable of safe velocity of flow in the channel.

To convey a peak flow on a given slope of a soil with given characteristics:

1- select the maximum permissible velocity according the proposed vegetation

(see Table T3)

2- Select a suitable value of roughness n coefficient according to the vegetation retardance class.

(see Tabla T4)

3- Calculate the hydraulic radius (r) form the Manning equation.

$$r = \left(\frac{vn}{S^{0.5}} \right)^{1.5}$$

Calculate the required cross section

4- $A = \frac{Q}{v}$

5- Calculated the design depth for a parabolic section

$$t = \left(\frac{A}{0.67d} \right)$$

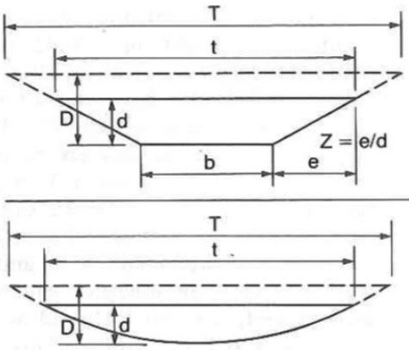
d≈1.5r

6- Calculate the top width for a parabolic section

7- Check that the capacity given by the design criteria is adequate

8- $Q = AV = 0.67tdv$

9- Add 20% freeboard to design depth



Trapezoidal	Area	$bd + Zd^2$
	Wetted perimeter	$b + 2d\sqrt{1 + Z^2}$
	Hydraulic radius	$\frac{bd + Zd^2}{b + 2d\sqrt{1 + Z^2}}$
	Top width	$t = b + 2dZ$ $T = b + 2DZ$
Parabolic	Area	$\frac{2}{3}td$
	Wetted perimeter	$t + \frac{8d^2}{3t}$
	Hydraulic radius	$\frac{t^2d}{1{\cdot}5t^2 + 4d^2}$ (approx.) $\frac{2d}{3}$
	Top width	$t = \frac{3a}{2d}$ $T = t(\frac{D}{d})^{1/2}$

Basic dimensions of common channel sections

After Morgan (1995)

Exersice Of Terrace Design

Design terraces for vineyard planting in an area with an average slope ranging between 11 and 25º (19.5 and 45%).

According to slope decide the areas which may be planted and decide the type of terraces to construct

- Draw drainage lines
- Terrace design:
- Spacing: use different empirical equations and compare the results
- Consider length of terrace, gradient of terrace channel
- Terrace channel capacity
- Waterways design
- Soil characteristics:
- Texture- Clay-loam (20-30% clay; < 50% sand)
- Soil depth: varies form 50-90 cm.
- Permeability: moderately slow (10-20 mm/h)
- Erosion: moderate erosion, with some dissection by runoff channels

Rainfall characteristics of the area: Annual rainfall 400 mm, mainly concentrated in a reduced number of events. Maximum intensities 100mm/h, with a 10 year return period.

Consider the possibility of having bare soil (due to water restrictions)

Basic procedure

1- Using aerial photographs, topographical maps and reconnaissance field surveys, determine the preliminary position of the grass waterways for the intakes to the tile drainage system. Where possible, place waterways in the natural depressions of the ground surface
2- Locate the main breaks of slope and any badly eroded or gullied areas. Terrace banks should be located on slope breaks and above eroded land
3- Determine the spacing of terraces using empirical formula or an equation to calculation critical slope length. Te computed spacing may be varied by 25-30% to allow for adjustments in position of terraces for conform with slope breaks and avoid eroded areas.
4- Determine terrace lengths. Terrace must be limited in length to avoid dangerous accumulations of runoff and large cross-sectional areas to the channels.
5- Determine terrace channels gradient. The gradient must be sleep sough to permit good drainage but gentle enough to permit non-erosive flow. It is impractical to vary the gradient continuously but changes may be made at approximately 100m intervals

6- Calculate required channel cross section
7- Adjust the position of the grass waterways if necessary to conform with maximum terrace length
8- Using contour maps and aerial photographs, plan the layout of the terrace system. Locate the top of key terrace. The catchment are above the top terrace should not exceed 1.2 ha. Terrace often begin at the ridge of high point on a spur and run away form the crest, turning parallel to it along the main slope. Locate other terraces in relation to the key terrace and in accordance with the design spacing , design length and gradient and in keeping with the slope breaks and eroded areas
9- Examine the layout. It is practical for farming? Can the smallest inter-terrace areas be worked economically ?
10- If necessary adjust the terrace layout to minimised point rows and to obtain and approximately parallel layout. Mark the areas which the plan requires cut and fill operation to give the parallel layout. Where parallel systems are used, the terrace spacing should be decreased to 0.67 VI to allow for greater deviations of the terraces from the contours.

Additional information: Look at tables

- Treatment oriented land capability classification in *Sheng. 1972*
- Manning coefficient for different land use and cover in *Morgan 1995*
- Permissive velocities for vegetated channels in *Morgan 1995*
- Manning coefficient for vegetated channels in *Morgan 1995*
- Typical scores for vegetation cover, soil and slope conditions to estimate the volume of peak runoff from small areas *in Morgan 1995*

Table 4. Treatment oriented land capability classification (adapted from Shens 1972)

Group	Class	Characteristics and recommended treatments
Suitable for tillage	C1	Up to 7º slope; Soil depth normally over 10 cm; Contour cultivation; Strip cropping; Broad-base terraces
	C2	Slopes 7-15%; Soil depth over 20 cm; Bench terracing (construction with bulldozers; use of four-heel tractors
	C3	Slopes 15-20º; soil depth over 20 cm; Bench terracing on deep soil (construction by small machines); silt-pits and shallower soils; use of small tractors or walking tractors.
	C4	Slopes 20-25º; soil depth over 50 cm; Bench terracing and farming operation by hand labour
	F	Slopes over 30º or over 255 where soil is too shallow for tree crops; maintain as forest land
Wetland, liable to flood; also stony land	P	Slopes 0-25º; Use of pasture
	F	Slope over 25º; Use as forest
Gullied land	F	Maintain as forest land

Table 5. Guide values for Manning's n (adapted from Morgan, 1995)

Slope / Soil depth	1. Gentlle sloping < 7º	2. Moderate sloping	3. Strongly sloing	4. Very strongly sloping	5. Steep	6.Very steep
Deep (D) >90 cm	C1	C2	C3	C4	FT	F
Moderately deep (MD) 50-90 cm	C1	C2	C3	C4 / P	FT / F	F
Shallow (S) 20-50 cm	C1	C2 / P	C3 / P	p	F	F
Very shallow < 20 cm	C1 / P	P	P	P	F	F

Land use of cover	Manning's n
Bare soil	
roughness depth < 25 mm	0.010-0.030
roughness depth 25-50 mm	0.014-0.033

roughness depth 50-100 mm	0.023-0.038
roughness depth > 100 mm	0.045-0.049
Bermuda grass –sparse to good cover	
very short (>50 mm)	0.015-0.040
vhort (50-100 mm)	0.030-0.060
medium (150-200)mm	0.030-0.085
long (250-600 mm)	0.040-0.150
very long (>600 mm)	0.060-0.200
Bermuda grass –dense cover	0.300-0.480
Other dense sod-forming grasses	0.390-0.630
Dense bunch grasses	0.150
Kudzu	0.070-0.230
Lespedeza	0.100
Natural rangeland	0.100-0.320
Clipped rangeland	0.020-0.240
Whet straw mulch	
2.5 t/ha	0.050-0.060
5.0 t/ha	0.075-0.150
7.5 t/ha	0.100-0.200
10.0 t/ha	0.100-0.200
Chopped maize stalks	
2.5 t/ha	0.012-0.050
5.0 t/ha	0.020-0.075
10.0 t/ha	0.023-0.130
Cotton	0.070-0.090
Wheat	0.100-0.300

Sorghum	0.040-0.110
Concrete or asphalt	0.010-0.013
Gravelled surface	0.012-0.030
Chisel-ploughed soil	
<0.6 t/ha residue	0.006-0.170
0.6-2.5 t/ha residue	0.070-0.340
2.5-7.5 t/ha residue	0.190-0.470
Disc-harrowed soil	
<0.6 t/ha residue	0.008-0.410
0.6-2.5 t/ha residue	0.100-0.250
2.5-7.5 t/ha residue	0.140-0.530
No tillage	
<0.6 t/ha residue	0.030-0.070
0.6-2.5 t/ha residue	0.010-0.130
2.5-7.5 t/ha residue	0.160-0.470
Bare mouldboard-ploughed soil	0.020-0.100
Bare soil tilled with coulter	0.050-0.130

After Petryk and Bosmajian (1975), Temple (19082) and Engman (1986)

Table 6. Maximum safe velocities (m/s) in channels based on covers expected after two seasons (adapted from Morgan, 1995)

Material	Bare	Medium grass cover	Very good grass cover
Very light silty sand	0.3	0.75	1.5
light loose sand	0.5	0.9	1.5
coarse sand	0.75	1.25	1.7
sandy soil	0.75	1.5	2.0
firm clay loam	1.0	1.7	2.3
stiff clay or stiff gravelly soil	1.5	1.8	2.5
coarse gravels	1.5	1.8	*
shale, hardpan, soft rock etc	1.8	2.1	*
hard cemented conglomerates	2.5	*	*

* Material is unlikely to yield a very good grass cover.

Intermediate values may be selected.

Properties of grass channel linings for good uniform stands*

Cover group	Estimated cover factor, CF	Covers tested	Reference stem density (stems/m^2)
Creeping grasses	0.90	Bermuda grass	5,380
		Centipede grass	5,380
Sod-forming grasses	0.87	Buffalo grass	4,300
		Kentucky bluegrass	3,770

		Blue grama	3,770
Bunch grasses	0.50	Weeping love grass	3,770
		Yellow blue stem	2,690
Legumes†	0.50	Alfalfa	5,380
		Lespedeza sericea	3,230
Annuals	0.50	Common *Lespedeza*	1,610
		Sudan grass	538

* Multiply the stem densities given by 1/3, 2/3, 1, 4/3 and 5/3 for "poor, fair, good, very good and excellent" covers respectively. The equivalent adjustment to CF remains a matter of engineering judgement until more data are obtained or a more analytical model is developed.

†For the legumes tested, the effective stem count for resistance (given) is approximately five times the actual count very close to the bed. Similar adjustment may be needed for other unusually large-stemmed and/or woody vegetation.

Table 7. Manning coefficient for vegetated channels
Values of Manning's n for vegetated channels

CI	Description	n
10.0	very long (over 600 mm) dense grass	0.06-0.20
7.6	long (250-500 mm) grass	0.04-0.15
5.6	medium (150-250 mm) grass	0.03-0.08
4.4	short (50-150 mm) grass	0.03-0.06
2.9	very short (less than 50 mm) grass	0.02-0.04

Table 8. Typical scores for vegetation cover, soil and slope conditions to estimate the volume of peak runoff for small areas (adapted form Morgan, 1995)

Catchment characteristics

Cover		Soil type and drainage		Slope	
Heavy grass or forest	10	Deep, well drained soils, sands	10	Very flat to gentle (0-3º)	5
Scrub or medium grass	15	Deep, moderately pervious soil, silts	20	Moderate (3-6º)	10
Vultivable lands	20	Soils of fair permeability and depth, loams	25	Rolling(6-9º)	15
Bare or eroded	25	Shallow soils with impeded drainage	30	Hilly or steep	20
		Medium heavy clays or rocky surface	40	Mountainous	25
		Impervious surfaces and waterlogged soils	50		

The value of the catchment characteristic (GC) for the problem catchment is calculated as follows:

Region	Factor values						Percentage area weigthing	Total
	Cover		Soil		Slope			
A	25	+	40	+	20	x	0.20	17.0
B	20	+	25	+	10	x	0.30	18.0
C	10	+	40	+	5	x	0.50	27.5
Catchment characteristics (CC)							=	62.5

Peak runoff as a function of catchment characteristics and area

A\CC	25	30	35	40	45	50	55	60	65	70	75	80
5	0.2	0.3	0.4	0.5	0.7	0.9	1.1	1.3	1.5	1.7	1.9	2.1
10	0.3	0.5	0.7	0.9	1.1	1.4	1.7	2.0	2.4	2.8	3.2	3.7
15	0.5	0.8	1.1	1.4	1.7	2.0	2.4	2.9	3.4	4.0	4.6	5.2
20	0.6	1.0	1.4	1.8	2.2	2.7	3.2	3.8	4.4	5.1	5.8	6.5
30	0.8	1.3	1.8	2.3	2.9	3.6	4.4	5.3	6.3	7.3	8.4	9.5
40	1.1	1.5	2.1	2.8	3.5	4.5	5.5	6.6	7.8	9.1	10.5	12.3

50	1.2	1.8	2.5	3.5	4.6	5.8	7.1	8.5	10.0	11.6	13.3	15.1
75	1.6	2.4	3.6	4.9	6.3	8.0	9.9	11.9	14.0	16.4	18.9	21.7
100	1.8	3.2	4.7	6.4	8.3	10.4	12.7	15.4	18.2	21.2	24.5	28.0
150	2.1	4.1	6.3	8.8	11.6	14.7	18.2	21.8	25.6	29.9	35.0	40.6
200	2.8	5.5	8.4	11.7	15.3	19.1	23.3	28.0	33.1	38.5	45.0	52.5
250	3.5	6.5	9.7	13.2	17.2	21.7	27.0	32.9	39.6	46.9	55.0	63.7
300	4.2	7.0	10.5	14.7	19.6	25.2	31.5	38.5	46.2	54.6	63.7	73.5
350	4.9	8.4	12.6	17.2	23.2	30.2	37.8	46.3	53.8	62.5	71.5	81.0
400	5.6	10.0	14.4	19.4	25.6	33.6	42.2	51.0	60.0	69.3	79.5	90.0
450	6.3	10.5	15.5	21.5	28.5	36.5	45.5	55.5	65.5	76.0	86.5	97.5
500	7.0	11.0	17.0	23.5	31.0	40.5	51.0	62.0	73.0	84.0	95.0	106.5

A is the area of the catchment in hectares, CC is the catchment characteristics from previous table, and the runoff (in cubic metres per second) is for a 10-year frequency

Notes:

Rainfall intensity:	tropical (high)	multiply by 1.0
	temperate (low)	multiply by 0.75
Catchment shape:	long, narrow	multiply by 0.8
	sqare/circular	multiply by 1.0
	broad, short	multiply by 1.25

Return period:	2 years	multiply by 0.90
	5 years	multiply by 1.0
	10 years	multiply by 1.0
	25 years	multiply by 1.25
	50 years	multiply 1.5

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Exercise 2: Land morphology changes and effects on vineyard development in the Priorat vineyard region

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Introduction

In the present exercise we study the effects of hillslope terracing on the development of vines in relation to land movements carried out during the process of terrace construction. We will analyze if the hypothesis assumed by viticulturists before they create a new terraced plantation, according to which the land movements and soil displacement involved in terrace construction do not affect the development of vines, is accomplished. The analysis is carried out in sample fields of the Priorat region (NE Spain) (Figure 1), where detailed digital terrain modelling of dates before and after terrace construction were available.

Study area

Two sample fields of 8.15 ha (the northern field) and 4.61 ha (the southern field) (Figure 1) were selected to study the effects of hillslope terracing on vine development. The elevation in these fields ranges from 290 to 480 m, with an average slope of 26.4º. The terracing of the fields was completed at the end of 2000 (the northern field) and at the beginning of 2003 (the southern field). After terracing, both fields were planted with vines of the Grenache variety in a pattern of about 2.5 x 0.6 m. Backhoe loaders and bulldozers were used to construct the terraces, following the usual criteria and methodology for new land transformations in the Priorat region. The terraces are of the linked bench type and were constructed without plans based on the expertise of the backhoe loader driver. The number of terraces, the spacing between them and the slope of the riser depended on the slope of the original ground surface and the target width of the bench, about 2.5 m, which allows two vine rows per bench. In the sample fields land movements resulted in terraces 2.94±0.9 m wide with riser heights of 4.8±3.0 m and an average slope of 39.4°±8.7°. All these characteristics make the selected field a typical location for extrapolating results to other plantations of the same characteristics in the region.

N. Evelpidou & T. de Figueiredo (eds.) *Soil Protection in Sloping Mediterranean Agri-Environments: lectures and exercises*. Instituto Politécnico de Bragança, Portugal, 2009

Figure 1: Study fields.

Exercise

The aim is to analyze the relationships between the terrain morphology change zones and the vigour of the vines planted on them. The null hypothesis assumed by viticulturists before they create a new terraced plantation is that the land movements and soil displacement involved in terrace construction do not affect the development of vines.

For that, start first the program ArcMap and observe the available layers:

- Start the program ArcMap from the start menu of Windows.
- Establish the current workspace and the scratch workspace: Activate the icon ArcTool Box and with the right button in ArcToolBox select Environments. Then, in General Settings, select the folder C:\GIS\PRIORAT for both current and scratch workspace.
- In the menu Tools, select Extensions and activate Spatial Analyst. This allows using this extension to work with raster data.
- In the menu View, select Toolbars and then Spatial Analyst. This will load the menu Spatial Analyst.
- In the menu Spatial Analyst, select properties and establish the folder C:\GIS\PRIORAT as the working directory.
- With the ADD DATA button add layers from the folder C:\GIS\PRIORAT

- With the right button in the group of Layers, establish in Properties the Map units (set to m) and the coordinate system (Predefined, Projected, UTM, Other GCS, European Datum 1950 UTM Zone 31 N).
- Zoom into the location of the study field (bottom right).
- Observe the available layers:
- DEM86: Digital elevation model surveyed on 1986 (2 m resolution)
- DEM03: Digital elevation model surveyed on 2003 (2 m resolution)
- QB04subset: Pan-sharpened Quickbird-2 satellite image of July 2004 (0.7 m resolution)
- QB06subset: Pan-sharpened Quickbird-2 satellite image of July 2006 (0.7 m resolution)
- Vine_Rows: Lines where vines are planted (raster format) (0.7 m resolution)
- Boundary.shp: Boundary of the study field (vector file)
- Mask_N.shp: Boundary of the northern field (vector file)
- Mask_S.shp: Boundary of the southern field (vector file)

Assessment of terrain morphology changes

The assessment of terrain morphology changes due to hillslope terracing will be based on relief reconstruction for a date before the construction of the terraces (1986) and after (2003). For that, photogrammetric restitution of aerial photographs has been previously carried out, deriving spot heights, 2 m-spaced contours and break lines to establish the form of the terraces and other geomorphological features, which were used to interpolate digital elevation models (DEMs) for both dates. The horizontal resolution given to the grids is 2 m.

(Q1) How can the magnitude and location of terrain morphology changes be computed from the DEMs?

The spatial operation to compute terrain morphology changes can be performed from the Raster Calculator option in the Spatial Analyst menu.

(Q2) How can the results of the operation performed be interpreted?

To determine zones of cut and fill we will reclassify the resulting layer from the previous operation according to the following criteria:

Cut: < -0.1 m

Fill: 0.1 m

No change: -0.1 to 0.1 m

Plant vigour calculation

Plant vigour in the study field can be monitored for the years 2004 and 2006 by means of the normalized difference vegetation index (NVDI) computed from Quickbird-2 satellite images. Quickbird-2 is a satellite operated by DigitalGlobe Inc. (Longmont, Colorado, USA) that acquires 0.61 m panchromatic and 2.44 m multispectral images at nadir, with 11 bit dynamic range. The spectral bandwidth of the data is 455 to 900 nm for the panchromatic band, 450-520 nm for the blue band, 520-600 nm for the green band, 630-690 nm for the red band and 760-900 nm for the near-infrared band.

For each year analyzed, standard panchromatic and multispectral were acquired. The images covered approximately 5.50 km x 12.75 km (70.17 km^2). The acquisition was performed in July of each year. The spatial resolution of the images was 0.70 m and 2.8 m (off-nadir) for the panchromatic and multispectral bands, respectively. The images were projected to the European Datum 1950 and the UTM 31n coordinate system, in which other geographic information used in the research was also expressed. The spatial resolution given to the images was 0.7 m, and the RMS errors of the geometric transformations were less than one pixel in all cases.

For each of the available images, the NDVI index can be computed from the

$$NDVI = \frac{\varphi_{NIR} - \varphi_{RED}}{\varphi_{NIR} + \varphi_{RED}}$$

following formula in the Raster Calculator option of Spatial Analyst.

where φ_{NIR} and φ_{RED} are the spectral reflectance measurements acquired in the near-infrared and red, respectively. By design, the NDVI itself thus varies between -1.0 and +1.0.

Perform the operations in the Raster Calculator to compute the NDVI of each year. For that, the near infrared and red bands or each year have to be loaded by separate in ArcMap. In addition, the bands have to be transformed to allow floating point operations by means of the function FLOAT, which can be applied in the Raster Calculator.

Extraction of NDVI values on vine rows

NDVI values for vine rows on each of the three image dates can be isolated from the original NDVI images. To do this, a mask of the vine rows (Vine_Rows layer) is available. This mask has to be applied to the NDVI images of each date to obtain the NDVI per planted row and date.

(Q3) Which operation must be performed to extract the NDVI values of the vine rows?

Apply the mask of the vine rows to the NDVI maps of each year.

Now the resulting NDVI-per-row maps have to be differenciated for the northern and southern fields. To do that, another mask operation has to be performed using the Mask_N and Mask_S shapefiles. However, first these vector files have to be rasterized using the same cellsize than the NDVI maps. This operation can be performed through the option Convert in the Spatial Analyst menu.

The result of these operations shoud be two NDVI-per-row maps, one for the northern field and one for the southern field.

Relationship between terrain morphology changes and plant vigour

Once the NDVI-per-row maps for the northern and southern fields have been created, the relationships between terrain morphology changes due to hillslope terracing and plant vigour can be established. This will consist of zonal statistics operations in Spatial Analyst.

Two type of analysis can be performed:

a) <u>Interfield plant vigour analysis:</u> This analysis considers the northern and southern fields as the spatial units in which to compare the plant vigour development. The null hypothesis assumed that there were differences in plant vigour in the two fields due to the different year of plantation (2001 in the northern field and 2003 in the southern field).

For that, perform zonal statistical operations in Spatial Analyst using as zone sets the mask of the northern and southern fields and as value raster the NDVI-per-row maps of each field. The results will be two .*DBF tables that summarize the NDVI statistics (minimum, maximum, mean, standard deviation and range) for the northern and southern fields respectively.

(Q4) Are there differences on plant vigour between the northern and southern fields? Which can be the main reason?

b) <u>Intrafield plant vigour comparison:</u> This considered the different elevation zones resulting from land terracing (defined in Table 1) as the spatial analysis units. The analysis was performed separately on the northern and southern fields. The null hypothesis assumed the non-existence of plant vigour differences in the fields as a result of cut and fill operations for terracing.

For that, perform zonal statistical operations in Spatial Analyst using as zone sets the cut/fill/no_change zones for each of the fields (northern and southern) and as value raster the NDVI-per-row maps of each field. The results will be two .*DBF tables that summarize the NDVI statistics (minimum, maximum, mean, standard deviation and range) for the zones (cut/fill/no_change) of the northern and southern fields respectively.

(Q5) Are there differences on plant vigour between the zones of the northern field? And in the zones of the southern field? Which can be the main reason?

Final layout

Prepare a Layout (map composition) with the satellite image and the boundary of the study field. The colour composite of the satellite image should be RGB432. Once prepared, the layout can be saved as an image or PDF file.

Layout preparation:

- In the VIEW menu, select LAYOUT VIEW.
- In the INSERT menu, select INSERT TITLE.
- Double click on the title created to change it. Write a title for the map composition to create. APPLY and ACCEPT. (It is also possible to change the font, size, color, etc., of the title).
- In the INSERT menu, select INSERT LEGEND.
- Click in LEGEND ITEMS - and add or to remove the layers that you wish that appear in the legend.
- Number of columns in the legend: 2 or 3 (depending on the items to show), Following …
- Title of the legend: LEGEND
- Following up to FINISHING
- Scroll the legend under the map with the mouse.
- In the VIEW menu, select DATA FRAME PROPERTIES. Select the option GRIDS to add a new georeferencing grid.
- NEW GRID
- MEASURE GRID: DIVIDE MAP INTO MAP UNITS
- Intervals. For example, indicate intervals of 200 m in X and Y
- Accept options by default up to finishing
- APPLY and ACCEPT
- To insert now the north arrow. Menu INSERT, NORTH ARROW. Select the one that is wished.
- To insert the scale bar. Menu INSERT, SCALE BAR. Select the one that is wished.

The layout should be ready to publish. Nevertheless, the user can, if it is wished, add some additional text, photographs, logos, etc...

Save the layout in PDF: Go to the menu *"File "*option *"export"* and select the option PDF.

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Soil Protection in Sloping Mediterranean Agri-Environments. The case study of the Penedès vineyard region

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Abstract

The present study case refers to the Penedès region, an area with a long tradition for vineyard cultivation. Vineyards are the main land use, representing 80% of the cultivated area. Most soil profiles have been truncated either by erosion or by land levelling. This is a frequent practice that is carried out to achieve larger and mechanised fields, which has involved the elimination of numerous soil conservation measures. This exercise proposes a methodology to evaluate and quantify terrace efficiency for sediment trap and avoid soil loss out of the fields.

Introduction

It is well known that water erosion causes major on-site as well as off-site damage and problems. The immediate, and most widely documented, on-site effects of erosion and runoff include soil and nutrient losses (Poesen and Hooke, 1997; Douglas et al., 1998; Corell et al., 1999; Steegen et al., 2001; Verstraeten and Poesen, 2002; Ng Kee et al., 2002; Ramos and Martínez-Casasnovas, 2004) and the long-term productivity loss of degraded soil at the plot level (Roose, 1976; Woodward, 1999). In the case of concentrated overland flow, and particularly during high intensity rainfalls, another immediate on-site effect in agricultural lands is the incision of rills and ephemeral gullies, which constitute the main drainage systems for a field, through which most water and sediment are discharged (Zheng and Huang, 2002).

The differences between rills and ephemeral gullies are not always very clear (Nachtergaele, 2001). The main differences are the variable position of rills across a slope, in contrast to the clearly channelised form of ephemeral gullies, which form few major natural waterways usually occurring in the same spots (Foster, 1986). Regarding size differences, the Soil Science Society of America (2001) defines rills as small channels of only several centimetres in depth, although other authors specify a critical cross-section of 0.093 m^2 to distinguish between rills and gullies (Poesen, 1993).

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Despite some differences in the position of rills and ephemeral gullies across the slope and size (Foster, 1986; Poesen, 1993), they are both ephemeral in nature, since they can easily be obliterated by normal tillage or filled by farmers because the scoured soil volume is not usually very large (Poesen, 1993; Woodward, 1999; Soil Science Society of America, 2001). In the case of ephemeral gullies, these tillage operations restore the original hollow, but leave potential zones for subsequent gully erosion by additional runoff events. Moreover, if ephemeral gullies are not controlled, they can grow into large gullies (Woodward, 1999; Bennet et al., 2000), producing significant local topographic changes in the medium-long term. Regarding the consequences or impacts of the ephemeral gullying cycle, some works stress that the repeated removal of top soil by the gullying process and the later filling operations (or obliteration by tillage) reduce the long-term productivity of the farmland, since soil to fill the gullies comes from areas adjacent to the channels, thus reducing top soil depth (Woodward, 1999). Filling operations help to mask the magnitude of short-term on-site effects such as sediment production and soil loss and may also make landscape denudation appear unnoticed, although some authors argue that it is progressive and substantial because of the recurrent spatial location of ephemeral gullies (Bennet et al., 2000).

The extensive use of soil loss prediction models during the 1980s to estimate soil losses in agricultural lands by sheet and rill erosion tended to overlook the contribution of ephemeral gully erosion in traditional soil erosion assessments (Poesen et al., 2003). It is only during the last two decades that these erosion phenomena have been recognised as being a major part of the erosional systems of cropland (Evans, 1993; Poesen et al., 2003). Recently, ephemeral gullies have been one of the most widely studied gully types, which is reflected in the number of works existing in the literature (Øygarden, 2003; Poesen et al., 2003; Martínez-Casasnovas et al., 2004). Some of those works aimed to determine the typology of ephemeral gullies for erosion risk mapping and as an aid to the selection of gully control measures (Poesen and Govers, 1990; Poesen, 1993; Casalí et al., 1999). Poesen and Govers (1990) subdivided ephemeral gullies according to their width-depth ratio (WDR), the ones with WDR >> 1 being those causing major crop damage though they are easily erased by conventional tillage. The development of this type of gully is related to high intensity and low-frequency rainstorms, as was also confirmed by Casalí et al., (1999).

Other authors have shown that the contribution of ephemeral gully erosion to total sediment production is far from negligible: 44-83% of total sediment production (Poesen et al., 1998; Martínez-Casasnovas et al., 2002), 30-100% of total soil loss (Casalí et al., 2000) or 21-271% of the estimated sheet and rill erosion (USDA-NRCS, 1997). These figures reveal that this erosion process may be a key issue to consider in some agricultural lands, particularly in cases in which crop vegetation partly covers the soil and cases with frequent erosive rainfall.

Considerable progress has been made in the field of ephemeral gullying. It is well known that ephemeral gully erosion is a process of a recurrent nature and that its contribution to total sediment production is far from negligible. However, there is a gap in other practical questions such as the assessment of changes that the ephemeral gullying cycle produces in the fields' landscape and also in the general economic balance of farms (the cost of erosion). The objective of this work is to apply a method developed by Martínez-Casasnovas et al. (2002) for assessing the topographic changes produced by water erosion (mainly ephemeral gullying) and by the subsequent filling by farmers. This method is based on the comparison of detailed multi-date topographic data (digital elevation models – DEMs). This is done in vineyard fields in which there are hillside ditches (broadbase terraces) that act as sediment traps to avoid major soil loss. The economic impact of erosion is analysed from the on-site perspective.

Methods

1. Characteristics of the study area

The Penedès region, located about 30 km southwest of Barcelona (41º28'N, 1º48'E, and at 260 m a.s.l.) (Fig. 1), is an area with a long tradition for vineyard cultivation, under the Designation of Origin (DO) Penedès. Vineyards are the main land use, representing 80% of the cultivated area. This area is part of the Penedès Tertiary Depression, with calcilutites (marls) as the main lithological material and occasional sandstones and conglomerates. The main soil tyoes in the area are: *Calcixerepts petrocálcicos, Typic Haloxeralfs, Palexeralfs petrocálcicos, Typic Haploxerepts, Typic Xerofluvents, Typic Haploxerepts,Typic Xerorthents, Typic Calcixerepts.* Most soil profiles have been truncated either by erosion or by land levelling. This is a frequent practice that is carried out to achieve larger and mechanised fields, which has involved the elimination of numerous soil conservation measures. The climate is Mediterranean, with a mean annual temperature of 15ºC and a mean annual rainfall of 550 mm. Rainfall mainly occurs in two periods: April to June and September to November. High-intensity rainstorms are frequent during the last period e.g. >100 mm h^{-1} in 5 min periods). The rainfall erosivity factor (R = kinetic energy x maximum intensity in 30-minute period) ranges between 1049 and 1200 MJ mm ha^{-1} h^{-1} yr^{-1} (Ramos, 2002).

Due to soil and rainfall characteristics, the area suffers important erosion processes, being possible to observe erosion processes either within the plots (sheet erosion, rills and ephemeral gullies) or out of the plots (big gullies), linked to the drainage systems. Some references referred to the effects of climate characteristics on soil erosion processes in the fields(Martínez-Casasnovas et al., 2002; Martínez-Casasnovas et al., 2005; Ramos & Martínez-Casasnovas, 2004; Ramos & Martínez-Casasnovas, 2006d; Ramos & Martínez-Casasnovas, 2006a; Ramos & Martínez-Casasnovas, 2009) and the effects of land different management practices carried out in the area, included land leveling (Ramos & Mulligan, 2005; Ramos & Martínez-Casasnovas, 2006c), as well as the erosion processes out of the fields (Martínez-Casasnovas et al., 2003; Martínez Casasnovas et al., 2004) are included in the reference list.

Figure 1*: Location of the study area*

2. Erosion and filling: quantification of field topography changes

Field topography changes due to water erosion (mainly concentrated runoff) and subsequent filling by farm machinery may be evaluated by subtraction of very high resolution multi-temporal DEMs (equivalent to a scale of 1:200). In this section it is presented an example referred to a vineyard plot, which has an area of 2.1 ha (175 m long x 125 m wide) (Figure 2). The average slope of the plot is 8.9%. The planar form of the slope is mainly rectilinear, with a few concavities where runoff concentrates. The plantation consists of trained vines in a 1.3 x 3.1 m pattern, which run along the contour (perpendicular to the maximum slope degree direction). Every eight rows there is a hillside ditch or broadbase terrace (locally named "rasa"). Their function is to intercept surface runoff and convey it out of the field via the side dirt tracks existing in the field, which act as drainage channels. In the upper part, surrounding the field, there is another drainage channel that intercepts runoff generated above it. These structures mean that there is no significant input of sediment into the field from the upslope or from neighbouring plots. Part of the sediment generated above the ditches is deposited in them and is later used and redistributed by farm machinery to fill ephemeral gullies developed as a consequence of the erosive rainfalls. Output of sediment occurs downslope, through several points where drainage channels and ephemeral gullies flow into the buffer area that surrounds the field (Figure 2). Here part of the sediment is deposited and the rest goes out of the system to the large gully located south of the field.

Three dates are considered in this analysis: a) 17/03/2000, before an extreme rainfall event that occurred on 10/06/2000, which caused most of the sediment production, redistribution and loss of sediment in the study period (March 2000 – July 2002) (Martínez-Casasnovas et al., 2002); b) 20/06/2000, just 10 days after the above-mentioned heavy storm, when incision caused by ephemeral gullies and sedimentation in the broadbase terraces could be easily mapped; and c) 25/07/2002, a later date, after the broadbase terraces had emptied and the ephemeral gullies had been filled, with the aim of assessing permanent topographic changes due to the extreme rainfall event in 2000 and other minor erosive rainfalls that occurred within the study period.

The three topographic surveys were carried out by the same team using a TOPCON GTS-303® total station. The precision of the distance measurement is 0.0105 m km-1 for a range of 2000 m. The number of points registered for each survey was 237 (17/03/2000), 288 (20/06/2000) and 297 (25/07/2002). These figures are above or within the range the number of points recommended for very detailed topographic surveys in the case of undulating or complex relief (150-250 points for a scale of 1:200) (Ojeda, 1984).

The topographic data are processed with the aid of the TCP (Autodesk®) software. For each date, 0.2 m interval contours were derived. Digital elevation models were constructed by means of a random triangulation using points along the contours and spot heights following the Delaunay method of triangulation. The Arc/Info Version 7.1.2 (ESRI®) software was used to do this. The resulting triangulated irregular networks (TINs) were used to compute 0.2 m resolution grids, which were later analysed with the ArcMap 8.3 (ESRI®) software.

To assess errors in the constructed elevation models, elevation differences in areas of stable terrain are compared for each two consecutive dates (17/03/2000 – 20/06/2000 and 20/06/2000 – 25/07/2002) (Table 1). Stable terrain areas were field tracks that surround the vineyard where rills were not observed after the erosive storms. In these areas, and in the absence of errors, the mean and variance of differences in elevation between two dates should be negligible (De Rose et al., 1998). Then, for each period, the accuracy elevation error can be estimated as twice the standard deviation of the mean elevation differences for the control areas, which represents the 95% confidence limits for soil displacement results (Table 1). According to Table 1, to correct for the detected errors an elevation of 0.0026 m was subtracted from each pixel of the 20/06/2000 DEM and 0.0027 m from the 25/07/2002 DEM.

Table 1. Control area data considered for the assessment of systematic errors in the comparison of digital elevation data of different dates.

Period	Control sites and % of total field area	Mean elevation difference	2SD
17/03/2000 – 20/06/2000	n = 6, 1%	+0.0026 m	±0.0017 m
20/06/2000 – 25/07/2002	n = 10, 1%	+0.0027 m	±0.0020 m

SD = Standard deviation

After these corrections, the DEMs are subtracted in the following way in order to assess the subsequent changes produced: [DEM(20/06/00) - DEM(17/03/00)] and [DEM(25/07/02) - DEM(20/06/00)]. These subtractions results in the two new grids with the altitude difference for each period. A negative value in the cells in the difference grids is interpreted as surface lowering, a positive value as deposition or filling, and a very low or zero value as no change. From these data, the sediment displaced (erosion or filling) is computed according to Equation 1.

Equation 1 $SD = (ED \cdot GR^2 \cdot Bd) / A$

Where:

SD = Sediment displaced (erosion if negative, or filling if positive) (Mg ha^{-1})

ED = Sum of the elevation differences (m)

GR = Grid resolution (m) (0.2 m in the present case study)

Bd = Bulk density of the soil top layer (Mg m^{-3}) (an average value of 1.25 Mg m^{-3} was considered according to field measures by Martínez-Casasnovas (1998) and Usón (1998))

A = Area of the field (ha)

During the first period (17/03/00 – 20/06/00), the farmer did not move soil or level the gullies. Only the usual tillage operations were performed: mechanical and chemical weeding and application of pesticides. Between these two dates, only low intensity rainfalls were recorded, causing no significant soil loss (rainfall characteristics described in 3.1). This means that the altitude differences between the first two surveys were due to soil erosion or deposition caused by the high intensity rainfall that occurred on 10/06/2000. In the second period (20/06/00 – 25/07/02), different soil movement operations were carried out in order to both redistribute the sediment deposited in the broadbase terraces and fill the ephemeral gullies that developed after the erosive rainfalls.

From the altitude difference grids and the application of Equation 1, different aspects related to the sediment displaced (erosion and filling), in addition to those specifically aimed at assessing ephemeral gully erosion on-site changes, were evaluated for both study periods. These are described in Table 2.

Table 2. Description of the displaced sediment categories

Sediment displaced category	Description
Sediment displaced due to erosion	For each study period, computed for the whole field as the sum of the negative values of the altitude differences.
Sediment displaced due to deposition or filling	For each study period, computed for the whole field as the sum of the positive values of the altitude differences.
General balance of sediment displaced	For each study period, sum of positive and negative altitude difference values. In other words, it is the balance between the sediment displaced due to erosion and that displaced due to deposition or filling.
Sediment displaced due to ephemeral gully erosion	Erosion: computed as the sum of elevation difference values < -0.1 m occurring in the first period (17/03/00 – 20/06/00), in which the extraordinary rainfall event that occurred on 10/06/00 is included. Filling: computed as the sum of elevation difference values > 0.1 m occurring in the second period (20/06/00 – 25/07/02).
Sediment deposited in or moved from hillside ditches	Deposited in: computed as the sum of elevation difference values > 0.1 m occurring in the first period (17/03/00 – 20/06/00). Moved from: computed as the sum of elevation difference values < -0.1 m occurring in the second period (20/06/00 – 25/07/02).
Sediment displaced due to rill and interrill erosion	Computed for the whole field as the sum of elevation difference values between -0.1 and 0.
Sediment deposited in other parts of the field different from hillside ditches or ephemeral gullies	Computed for the whole field as the sum of elevation difference values between 0 and 0.1.

As shown in Table 2, we have considered ephemeral gullies to be the channels between 0.1 and 0.5 m. As stated in the introduction section, differences between rills and ephemeral gullies are not always very clear (Nachtergaele, 2001). Gullies are classically defined as channels that are too deep to easily ameliorate with ordinary farm machinery, typically ranging from 0.5 m to 25-30 m (Soil Society of America, 2001). In the 1980s the term ephemeral gully erosion was introduced to include concentrated flow erosion that was larger than rill erosion but smaller than classical gully erosion (Poesen et al., 2002). Subsequently, the Soil Society of America (2001) defined ephemeral gullies as small channels eroded by concentrated overland flow that can easily be filled by normal tillage, reforming again in the same location by additional runoff. This definition, however, does not characterise the size of ephemeral gullies, although it seems that they have to be smaller than permanent gullies (< 0.5 m depth). Further bibliographic revision shows different conceptions on ephemeral gully sizes, which demonstrate no wide agreement on dimensions for distinguishing ephemeral gullies from rills. Poesen (1993) and Poesen et al. (1996, 2002) considered gullies, and distinguished gullies from rills, as channels deep enough to interfere with, and not to be obliterated by, normal tillage operations.

These authors used the criteria proposed by Hauge (1977) to distinguish gullies from rills, which consider a critical cross-sectional area of 0.093 m^2 as the threshold between rills and gullies. Poesen et al. (1996) argued that this cross-sectional area is perceived by farmers as a critical channel size above which the channels start to interfere with the trafficability of the land. Later, Vandekerckhove et al. (1998) used this cross-sectional area to distinguish between rills and ephemeral gullies, although, by former definitions, ephemeral gullies do not interfere with farm machinery since they can easily be obliterated. On the other hand, Casalí et al. (1999) considered ephemeral gullies to be channels with less cross-sectional area than the threshold applied by Vandekerckhove et al. (1998). In this respect, Casalí et al. (1999) described that ephemeral gully cross-sections in southern Navarra (Spain) ranged between 0.013 and 0.09 m^2, with the largest gullies near to 0.16 m^2. The depth of these ephemeral gullies was very variable, but most of them ranged between 0.1 and 0.5 m. Therefore, according to this discussion and to the opinion of Poesen et al. (2002), which recognises that the transition from rill erosion to ephemeral gully erosion to classical gully erosion represents a continuum, and any classification of related erosion forms is to some extent subjective, in the present work we follow the criteria used by Casalí et al. (1999). They seem more realistic and better adjusted to the definition of an ephemeral gully than those used by Vandekerckhove et al. (1998)—who also used an arbitrary threshold established to distinguish between rills and gullies in general—and agree with the field observations of size of ephemeral gullies in the Penedès vineyard region.

Results

1. Topographic changes due to erosion and filling

The results related to sediment displaced in both study periods (first period 17/03/2000 – 20/06/2000 and second period 20/06/2000 – 25/07/2002) are summarised in Table 3. The first period is characterised by a clear negative balance of the elevation differences, which is related to the extreme rainfall event that occurred on 10/06/2000. This event produced a net soil loss of

207±21 Mg ha-1 (Martínez-Casasnovas et al., 2002). The positive balance of the second period (90±25 Mg ha-1), however, confirms that part of the sediment displaced in the first period out of the field, as well as part of the sediment moved during the second period, was taken back and redistributed over the field by farm machinery. This sediment is deposited in the buffer zone located around the bottom of the field before it reaches the permanent drainage system (Figure 1). This positive balance must be understood as the result of the start point, just after a major erosion event, and the end point, after the redistribution of soil onto the field, although in the long run, as confirmed here below, there is a general negative balance.

Table 3. Summary of the sediment displaced categories for each period considered.

Description	Period 17/03/00 – 20/06/00	Period 20/06/2000 – 25/06/02
Sediment displaced due to erosion	-828±19 m^3	-543±21 m^3
	-487±13 Mg ha^{-1}	-320±12 Mg ha^{-1}
	Area= 53.8% of the field	Area= 49.4% of the field
Sediment displaced due to deposition or filling	476±17 m^3	695±22 m^3
	280±10 Mg ha^{-1}	410±13 Mg ha^{-1}
	Area= 46.3% of the field	Area= 50.6% of the field
General balance	-352±36 m^3	152±42 m^3
	-207±21 Mg ha^{-1}	90±25 Mg ha^{-1}
Sediment displaced due to ephemeral gully erosion	-478±6 m^3	352.5±5 m^3
	-282±4 Mg ha^{-1}	208±3 Mg ha^{-1}
	Area=15% of the field	Area= 11.4% of the field
	Represents 58% of the sum of negative values	Represents 51% of the sum of positive values
Sediment deposited in or moved from hillside ditches	111±2 m^3	-192±3 m^3
	65±1 Mg ha^{-1}	-113±2 Mg ha^{-1}
	Area= 4.2% of the field	Area= 6.2% of the field
	Represents 23% of the sum of positive values	Represents 35% of the sum of negative values
Rill & Interrill erosion balance	-350±14 m^3	-351±18 m^3
	-206±8 Mg ha^{-1}	-207±11 Mg ha^{-1}
Zones with negative differences	Area= 39% of the field	Area= 43.2% of the field
(-0.1 – 0 m)	Represents 42% of the sum of negative values	Represents 64.6% of the sum of negative values
Zones with positive differences	341±15 m^3	343±17 m^3
	201±9 Mg ha^{-1}	202±10 Mg ha^{-1}
(0 – 0.1 m)	Area= 42.1% of the field	Area= 39.3% of the field
	Represents 71.6% of the sum of positive values	Represents 49.3% of the sum of positive values

Most of the sediment displaced in the first period, 282±4 Mg ha^{-1} (which represent 58% of the sum of negative values), was due to concentrated surface runoff, which caused surface lowering (ephemeral gullies) of up to 0.4-0.5 m in some parts of the field, mainly located where local topographic concavities exist (Figure 2). The ephemeral gullies that formed had a width-depth ratio (WDR) >> 1 (between 15 and 30). This agrees with the results of Poesen and Govers (1990) and Casalí et al. (1999), who found that this type of gully is related to high intensity and low-frequency rainstorms and causes major crop damage, but is easily erased by conventional tillage. In the present case study, in which the field is planted with vines, the damage to the crop was not as great as in the case of a crop totally covering the soil surface. Only the vines located along the gully paths were affected by the scouring, in some cases up to 30 cm, but they were not rooted out. Roots of the upper 25 cm are systematically eliminated by tillage operations to force the vines to root deeper into the soil, where they have available water. Nevertheless, a lesser development of the plants located in the concentrated runoff paths is observed in the field in comparison with plants located in other positions.

Figure 2: *Altitude differences (m) in the first period (17 March 2000–20 June 2000). Detail of sediment trapped in pools and ponds (hillside ditches) and sediment scoured by ephemeral gullies*

During the second period, although some of the rainfalls recorded in autumn 2001 presented a relatively high erosive potential, the altitude difference balance in the field within the period was positive. Ephemeral gullies were filled with part of the sediments deposited in the hillside ditches (Figure 3) and in the lower part of the buffer zone that surrounds the field. This is indicated in Table 3, which shows that about 208±3 Mg ha^{-1} was deposited along the ephemeral gullies that developed during the erosive rainfalls of the first and second period.

However, the general balance at the locations where ephemeral gullies recurrently occur is negative (74±3 Mg ha^{-1}), indicating that, although the farmer is filling the gullies after erosive rainfall events, concentrated surface runoff is producing a progressive surface lowering of these concavities. This agrees with authors such as Bennet et al. (2000), who state that, although filling operations may make landscape denudation appear imperceptible, surface lowering is progressive and substantial in the zones of recurrent occurrence of ephemeral gullies.

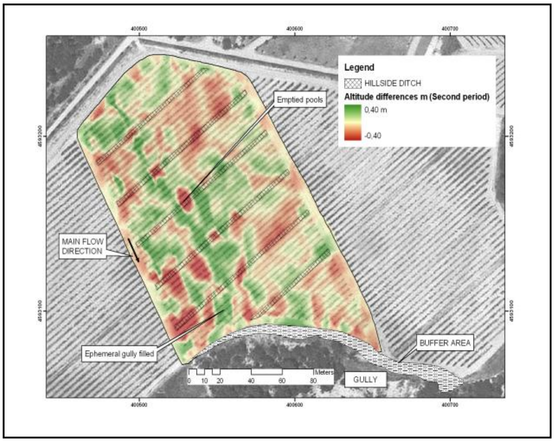

***Figure 3**: Altitude differences (m) in the second period (20 June 2000–25 July 2002). Detail of emptied pools (hillside ditches) and filled ephemeral gullies.*

Another aspect confirmed by this research is the dual role played by hillside ditches. Although their main function is to intercept surface runoff and convey it out of the field (Ramos and Porta, 1997), the results show that they also function as sediment traps. This occurs in pools or local depressions within the ditches and in the immediate surrounding area as a consequence of ponding effects, as also observed by Beuselinck et al. (2000). After the extreme rainfall event of 10/06/2000, hillside ditches trapped about 65±1 Mg ha^{-1} (23% of the sediment deposited within the field). This sediment was redistributed during the second period to other parts of the field (mainly to fill ephemeral gullies). This is shown in Table 3, which indicates an emptying of these drainage structures and ponds of 192±3 m^{-3}, equivalent to a sediment mass of 113±2 Mg ha^{-1}. The difference between the sediment deposited in the first period and the sediment emptied in the second period (48±2 Mg ha^{-1}) must be interpreted as deposition caused by the erosive rainfalls during the latter, in which some high intensity events occurred (see Section 3.1). In relation to ephemeral gully filling, sediment trapped in hillside ditches represents 54% of the material used for this task in the second period (113±2 Mg ha^{-1} out of 208±3 Mg ha^{-1}) (Table 3). This indicates the importance of implementing and maintaining these drainage structures in vineyard plantations, since in the last decade a lot of them have been removed in the study area in favour of vineyard mechanisation. Although in a different crop context, other authors have stressed the importance of vegetation-controlled deposition for the spatial distribution of deposited sediment along the slopes and on sediment delivery within the catchment (Beuselinck et al., 2000). This practice would be interesting to implement in the vineyard fields of the study area, even in alternate rows, to avoid major soil loss.

Regarding elevation differences of between -0.1 and 0.1 m, which can be attributed to rill and interrill erosion processes, tillage operations or a combination of the two, the sediment displaced in the two periods is of about the same magnitude. Overall, the balance of these processes shows a net soil loss of about 10±9 Mg ha^{-1}. This reveals both the importance of the first period for its erosive potential, since the amount of sediment displaced in this period is almost the same as that moved in the second, longer period, and the importance of ephemeral gully erosion as the main process causing soil loss in the study area.

The study allows to be concluded that although farmers fill ephemeral gullies after erosive rainfall events, recurrent concentrated surface runoff is producing a progressive surface lowering of the zones where ephemeral gullies develop. This may appear imperceptible, but surface lowering could be substantial in the medium-long term. The general balance at the locations where ephemeral gullies recurrently occur was negative (74±3 Mg ha^{-1}).

The research also assessed the efficiency of hillside ditches as sediment traps, although their main role is to convey the excess drainage water out of the field. A total of 113±2 Mg ha^{-1} deposited in these structures during the first study period was used to fill ephemeral gullies, which represents 54% of the material used for this task in the second period. This indicates the importance of implementing these conservation practices in new plantations as well as maintaining the ones existing in existing plantations, as against the widespread practice during the last few years of eliminating them in favour of vineyard mechanisation.

2. Cost of erosion

According to the information recorded and provided by the farmer, from 20 June 2000 to 25 July 2002 (the second period), about 15 h ha^{-1} was necessary to redistribute the sediment from the hillside ditches and from the buffer zone to the field. In total, this represented a cost of 381.90 €, or an average cost of 180 € ha^{-1} $year^{-1}$. Taking as a reference the year 2002, the sales of the grapes produced in the field amounted to 7710 €. The cost of erosion, assessed in this case as the cost of the operations necessary to redistribute the sediment over the field and to repair the hillside ditches, represented 5% of the income. This is probably an underestimation, since other indirect costs of erosion should also be considered: loss of nutrients.

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Exercise: Sediment trap efficiency of broadbase terraces in the Penedès vineyard region (NE spain)

Introduction

The main best management practice in the Penedès vineyard region (NE Spain) for runoff control are the broadbase terraces or hillside ditches locally called 'rases' (Figure 1). These are traditional runoff control measures that, during the last decades, have been progressively removed in order to create new modern vineyard plantations adapted to mechanization. Although the main function of these terraces is to convey the excess of runoff out of the field, it has been observed that they also actuate as sediment traps. However, their efficiency as sediment traps has not been assessed, which could be an important argument to implement them in the new and mechanized plantations.

In this respect, the present exercise applies a method developed for assessing the topographic changes produced by concentrated flow erosion and their filling by farmers to measure the sediment trap efficiency of broadbase terraces. The method is based on the comparison of multi-date detailed topographic data (digital elevation models, DEMs). In the case study, 0.20 m spatial resolution of March 2000, June 2000 and July 2002 were used.

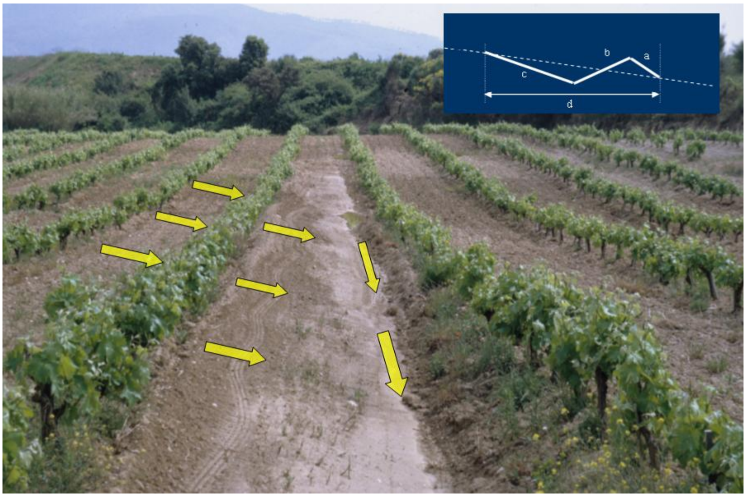


Figure 1: Example of broadbase terrace or hillside ditch ('rasa') in a vineyard field.

Study area

The study field is located in the Penedès region (Catalonia, Spain) (41º 28'N, 1º 48'E) (Figure 2). Vineyards are the main land use of the region, representing 80% of the cultivated area. This area is part of the Penedès Tertiary Depression, with calcilutites (marls) as the main lithological material and occasional sandstones and conglomerates. According to Soil Taxonomy (Soil Survey Staff, 1998), the most frequent soils are classified as *Typic Xerorthents* and *Typic Calcixerepts* (Martínez-Casasnovas, 1998). In recent decades, land levelling has been a frequent practice in the study area with the aim of making larger and more-easily mechanised fields, which has involved the elimination of numerous soil conservation measures. Most soil profiles have been truncated either by erosion or by land levelling. The climate is Mediterranean, with a mean annual temperature of 15º C and a mean annual rainfall of 550 mm (Ramos and Porta, 1994). Rainfall mainly occurs in two periods: September to November and April to June. High-intensity rainstorms are frequent during the first period (e.g. >100 mm h^{-1} in 5-min periods). The rainfall erosivity factor (R) ranges between 1049 and 1200 MJ mm ha^{-1} h^{-1} yr^{-1} (Ramos, 2002).

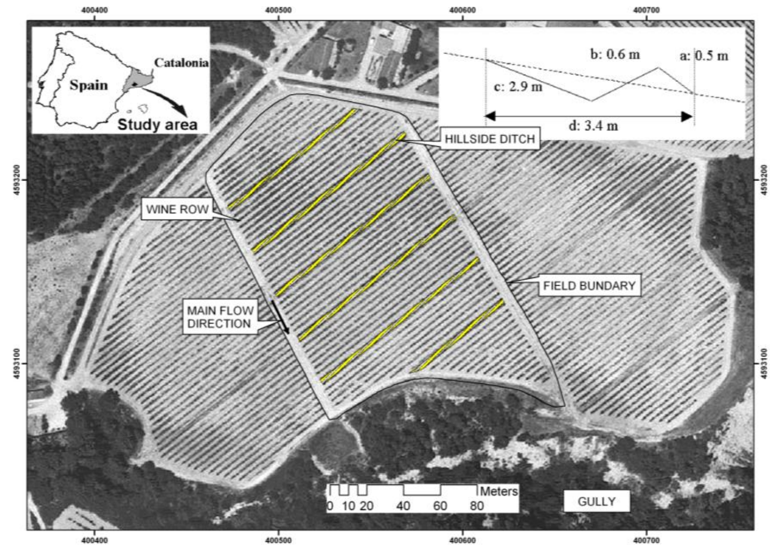


Figure 2: Location and characteristics of the study field. In the box: detail of a hillside ditch.

The case study vineyard has an area of approximately 2.12 ha (Figure 2). The average slope of the plot is 8.9%. The plantation consists of trained vines, in a 1.3 m x 3.1 m pattern, which run along the contour (perpendicular to the maximum slope direction). Three grape varieties are planted in the field: Macabeo, Chardonay and Parellada. Every eight rows, there is a hillside ditch or broadbase terrace. Their function is to intercept surface runoff and convey it out of the field. Part of the sediment generated above these ditches is deposited in them and is later used and redistributed by farm machinery to fill ephemeral gullies caused by erosive rainfalls. Output of sediment occurs downslope, through several points where drainage channels and ephemeral gullies flow into the buffer area that surrounds the field. Here part of the sediment is deposited and the rest goes out of the system to the large gully located south of the field.

Material and methods

Field topography changes due to water erosion (mainly concentrated runoff) and subsequent filling by farm machinery were evaluated by subtraction of very high resolution multi-temporal DEMs (equivalent to a scale of 1:200). Three dates were considered:

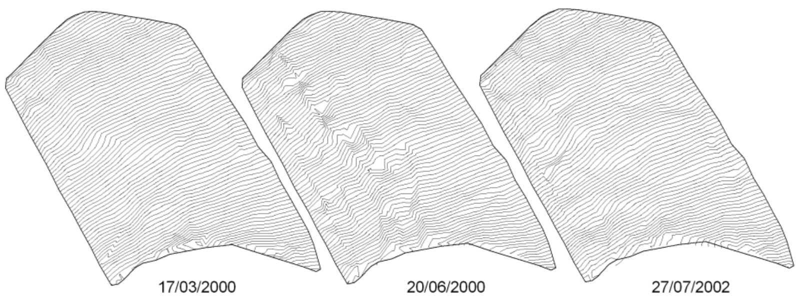
a) 17/03/2000, before an extreme rainfall event that occurred on 10/06/2000, which caused most of the sediment production, redistribution and loss of sediment in the study period (March 2000 – July 2002) (Martínez-Casasnovas et al., 2002)

b) 20/06/2000, just 10 days after the above-mentioned heavy storm, when incision caused by ephemeral gullies and sedimentation in the broadbase terraces could be easily mapped

c) 25/07/2002, a later date, after the broadbase terraces had emptied and the ephemeral gullies had been filled, with the aim of assessing permanent topographic changes due to the extreme rainfall event in 2000 and other minor erosive rainfalls that occurred within the study period.

The three topographic surveys were carried out by the same team using a TOPCON GTS-303® total station. The precision of the distance measurement is 0.0105 m km^{-1} for a range of 2000 m. The number of points registered for each survey was 237 (17/03/2000), 288 (20/06/2000) and 297 (25/07/2002). These figures are above or within the range the number of points recommended for very detailed topographic surveys in the case of undulating or complex relief (150-250 points for a scale of 1:200) (Ojeda, 1984). The topographic data were processed with the aid of the TCP (Autodesk®) software. For each date, 0.2 m interval contours were derived.

Digital elevation models were constructed by means of a random triangulation using points along the contours and spot heights following the Delaunay method of triangulation. The Arc/Info Version 7.1.2 (ESRI®) software was used to do this. The resulting triangulated irregular networks (TINs) were used to compute 0.2 m resolution grids, which will be analysed with the ArcMap (ESRI®) software.



(Q1) By visual interpretation of the contour maps, Do you think there are important changes in the morphology of the field between the three dates?

Exercise

1. Visualisation of data

- Start the program ArcMap from the start menu of Windows.
- Establish the current workspace and the scratch workspace: Activate the icon ArcTool Box and with the right button in ArcToolBox select Environments. Then, in General Settings, select the folder C:\GIS\PENEDES for both current and scratch workspace.
- In the menu Tools, select Extensions and activate Spatial Analyst. This allows using this extension to work with raster data.
- In the menu View, select Toolbars and then Spatial Analyst. This will load the menu Spatial Analyst.
- In the menu Spatial Analyst, select properties and establish the folder C:\GIS\PENEDES as the working directory.
- With the ADD DATA button add layers from the folder C:\GIS\PENEDES
- With the right button in the group of Layers, establish in Properties the Map units (set to m) and the coordinate system (Predefined, Projected, UTM, Other GCS, European Datum 1950 UTM Zone 31 N).
- Zoom into the location of the study field (bottom right).
- Observe the available layers:
  - R170300: Digital elevation model surveyed on 17/03/2000
  - R200600: Digital elevation model surveyed on 20/06/2000
  - R250702: Digital elevation model surveyed on 25/07/2002

- R_ditches.shp: Broadbase terraces along the study field (vector file)
- R_field.shp: Boundary of the study field (vector file)
- Ephemeral_gully.shp: Central line of the ephemeral gullies created in the first period.
- OF5MV50SD0F280121SS0R071.SID: Orthophoto of the study area (1:5000)

2. Elevation differences in the periods [170300-200600] and [200600-250702]

The first phase in the calculation to the determine the efficiency of broadbase terraces in trapping sediments by means of multi-date DEM analysis is to compute the elevation differences in each period. However, the simple differencing of two date DEMs may induce to errors if possible systematic errors in the DEM construction process are not considered.

(Q2) What are systematic errors? How can systematic errors be produced in the process of data acquisition for DEM construction?

Systematic errors will be assessed by comparison of the two DEMs in areas of known stable terrain between the two dates. Stable terrain areas are field tracks that surround the vineyard where rills were not observed after the erosive storms. In absence of errors, the mean and the variance of the elevation differences in those areas should be negligible.

a. Definition of stable terrain areas

- Stable terrain areas have to be digitized as polygons.
- Start ArcCatalog from the star menu of Windows or from ArcMap.
- Select de working directory C:\GIS\PENEDES and go to the menu File.
- In New, select Shapefile and then write the name 'Stable_Areas', and select the feature type polygon.
- Go again to ArcMap and add the layer Stable_Areas.shp
- This layer does not contain polygons. They have to be digitized on screen.
- Activate the menu Editor from the menu View, Toolbars.
- In Editor, select start Editing and create a new feature in the layer Stable_Areas.shp
- Digitize around 10 small polygons on the field tracks that surround the vineyard.
- Once digitized, open the attribute table of the layer (right button on top of the name of the layer) and assign a unique identifier (number) to each polygon. Then, stop editing in the Editor menu.

i. Assessment of systematic errors

As mentioned above, in the control areas and in the absence of errors, the mean and the variance of the elevation differences should be negligible. Otherwise, the mean of the differences between two dates should have to be added to one of the DEMs to correct the errors.

- Compute the elevation differences for the period [170300-200600]:
- In the menu Spatial Analyst, select Raster calculator and write:
- dif2006_1703= [r200600] – [r170300]
- In the menu Spatial Analyst, select Zonal statistics and indicate:
- Zone dataset: Stable_Areas
- Zone field: Id
- Value raster: dif2006_1703
- Click Join output table to zone layer

(Q3) How must be interpreted this table? Which field is relevant to know the elevation differences in each control polygon?

The table (in *.DBF format) can be opened in Excel. In Excel, compute the average of the MEAN field.

The average value of the MEAN field tells us the magnitude of the systematic errors between the two DEMs. This value will be added or subtracted to one of the DEMs to correct the errors.

(Q4) For example, if the average of means of the elevation difference values ([r200600] – [r170300]) in the control areas is -0.05 m, which operation will have to be done to correct the DEMs for the systematic errors?

By means of the raster calculator, subtract or add the calculated value to one of the DEMs to correct for the error. Give a different name to the corrected DEM.

Repeat the same for the period [200600-250702]

ii. Elevation differences and erosion/deposition

After these corrections, and by means of the raster calculator, subtract the the DEMs in the following way in order to assess the subsequent changes produced: ([200600] – [170300]) and ([250702] – [200600]).

(Q5) Interpretation of results: How can be negative values interpreted? And positive values? And zero or close to zero values?

From the difference elevation grids for each period, the sediment displaced (erosion or deposition) can be computed:

(Q6) How the balance between erosion and deposition within the field can be known for each period?

Perform the operations to solve question 6 and with the results apply the following formula to know the soil that has been eroded or deposited in the field in each of the two periods.

Equation $SD = (ED \cdot GR^2 \cdot Bd) / A$

Where:

SD = Sediment displaced (Mg ha^{-1})

ED = Sum of the elevation differences (m)

GR = Grid resolution (m) (0.2 m in the present case study)

Bd = Bulk density of the soil top layer (Mg m^{-3}) (an average value of 1.25 Mg m^{-3} was considered according to field measures by Martínez-Casasnovas (1998) and Usón (1998))

A = Area of the field (2.12 ha)

b. Sediment displaced by ephemeral gullies and sediment deposited to fill of ephemeral gullies after the high intensity rainfall

During the first period (17/03/00 – 20/06/00), the farmer did not move soil or level the gullies in the field. Only the usual tillage operations were performed: mechanical and chemical weeding and application of pesticides. Between these two dates, only low intensity rainfalls were recorded, causing no significant soil loss. This means that the altitude differences between the first two surveys were due to soil erosion or deposition caused by the high intensity rainfall that occurred on 10/06/2000. In the second period (20/06/00 – 25/07/02), different soil movement operations were carried out in order to both redistribute the sediment deposited in the broadbase terraces and fill the ephemeral gullies that developed after the erosive rainfalls.

Locate the areas where ephemeral gully erosion occurred in the period (17/03/00 – 20/06/00). For that, have into account that ephemeral gullies are considered be the channels between 0.1 and 0.5 m (elevation differences < -0.1 m).

According to the equation: $SD = (ED \cdot GR^2 \cdot Bd) / A$, compute the soil displaced by ephemeral gully erosion.

Locate the areas that were filled during the second period (20/06/00 – 25/07/02). Look for the elevation differences > 0.1 m occurring in the second period.

According to the equation: $SD = (ED \cdot GR^2 \cdot Bd) / A$, compute the soil displaced by ephemeral gully erosion.

(Q7) How much soil has been displaced by ephemeral gullies? How much soil was deposited in the second period in the zones affected by ephemeral gullies in the first period? Which is the balance?

c. Sediment deposited in or moved from the broadbase terraces

- Locate the areas where sediment was deposited in the period (17/03/00 – 20/06/00). For that, have into account that those areas are those with elevation difference values > 0.1 m.
- According to the equation: $SD = (ED \cdot GR^2 \cdot Bd) / A$, compute the soil deposited in those areas.
- Locate the areas where soil was taken to be redistributed over the field in the second period by looking for the elevation differences < -0.1 m in the period (20/06/00 – 25/07/02).
- According to the equation: $SD = (ED \cdot GR^2 \cdot Bd) / A$, compute the soil deposited in those areas.

(Q8) How much soil was deposited in the terraces in the first period? How much soil was redistributed over the field during the second period? Which is the balance?

(Q9) From the above results, do you consider that is the implementation and maintenance of broadbase terraces justified?

d. Final layout

To present the results, prepare a Layout (map composition) of the elevation differences in both periods. Once prepare, the layout can be saved as an image or PDF file.

- Layout preparation:
- In the VIEW menu, select LAYOUT VIEW.
- In the INSERT menu, select INSERT TITLE.
- Double click on the title created to change it. Write a title for the map composition to create. APPLY and ACCEPT. (It is also possible to change the font, size, color, etc., of the title).
- In the INSERT menu, select INSERT LEGEND.
- Click in LEGEND ITEMS - and add or to remove the layers that you wish that appear in the legend.
- Number of columns in the legend: 2 or 3 (depending on the items to show), Following …
- Title of the legend: LEGEND
- Following up to FINISHING
- Scroll the legend under the map with the mouse.

- In the VIEW menu, select DATA FRAME PROPERTIES. Select the option GRIDS to add a new georeferencing grid.
- NEW GRID
- MEASURE GRID: DIVIDE MAP INTO MAP UNITS
- Intervals. For example, indicate intervals of 200 m in X and Y
- Accept options by default up to finishing
- APPLY and ACCEPT
- To insert now the north arrow. Menu INSERT, NORTH ARROW. Select the one that is wished.
- To insert the scale bar. Menu INSERT, SCALE BAR. Select the one that is wished.

The layout should be ready to publish. Nevertheless, the user can, if it is wished, add some additional text, photographs, logos, etc...

Save the layout in PDF: Go to the menu "*File* "option "*export*" and select the option PDF.

Gully erosion in winter crops: a case study from Bragança area, NE Portugal

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Foreword

This text is an adapted and extended version of a poster presentation, quoted below, and was also the subject of a lecture prepared for SPinSMEDE 2008 edition. Discussion of this case study, although a very important part of the lecture, is not included in this text. Quotation is: Figueiredo, T. de, Poesen, J., Vandekerckhove, L., Oostwoud-Wijdenes, D., Araújo, J. 2000. Contribution of ephemeral gullies to erosion on cultivated areas: field measurements in four small catchments in Bragança, NE Portugal. Poster presented to International Symposium on Gully Erosion under Global Change, Catholic University of Leuven, Belgium, April 16-19, 2000 (book of abstracts).

Introduction

In Northeastern Portugal, a region where steep slopes dominate and most soils are thin, acid and highly stony, soil erosion affects the sustainability of agricultural and forest areas. Conversely, cultivation practices may strongly influence erosion rates. Measurements at plot scale, in the region, show that interrill erosion rates are normally low, due to protection provided by surface rock fragments.

At small catchment scale, however, linear erosion features are commonly observed in fields, meaning that conditions for erosive overland flow generation occur. Empirical observation indicates that ephemeral gullies affect mainly cultivated areas and that their occurrence depends on the combination of crop cover status and rainfall characteristics.

The relative importance of linear erosion is not known in the regional context. The most affected areas, and for which damage has more evident consequences, are cereal fields. In order to have a quantitative insight on the magnitude of linear erosion, field measurements were performed in four small cultivated catchments in the Bragança area (NE Portugal).

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***Figure 1**: Location map of study area.*

Study area and methodology

1. The agri-environment

At Bragança (42ºN, 7ºW, 650m elevation), mean annual Temperature (T) and Precipitation (P) are 11.9ºC and 740mm, respectively. Climate is Mediterranean sub-humid (Koppen Csa). Summers are hot and dry (highest monthly T>20ºC and Summer P<10 % annual P). Autumn and winter correspond to the wet semester (about 70 % annual P).

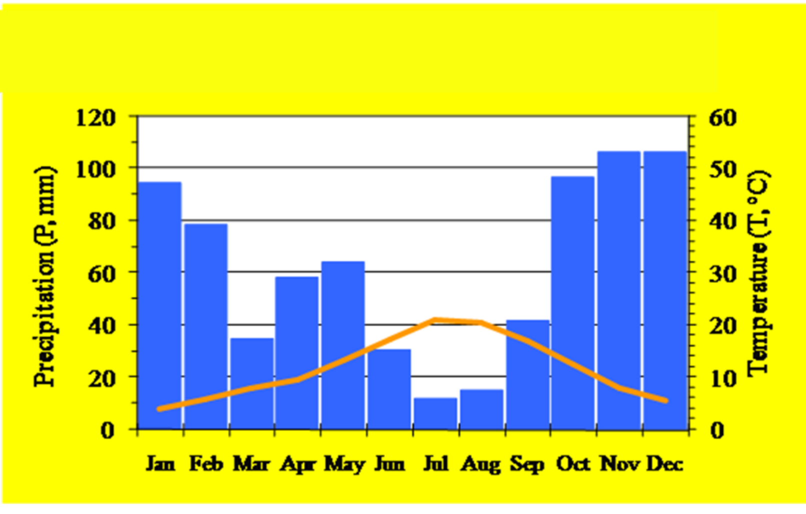

***Figure 2**: Monthly average Temperature and Precipitation at Bragança.*

Rolling landforms dominate, with gentle to moderately steep slopes. The area is a wide plateau (750 to 900m altitude), strongly dissected by the Sabor river system, from which rise three main elevations: Serra de Montesinho (1483m), Serra da Nogueira (1318m) and Serra da Coroa (1272m).

Schists (mostly Silurian) dominate around Bragança area. The Bragança complex is composed by a Precambrian dark and green schists area, patched by pre-Hercinic basic and ultramaphic rocks. Pliocenic sedimentary deposits, Hercinic granites and sparse Quartzitic crests are also found.

Dystric Leptosols (schist derived) are dominant. Chromic Luvisols (derived from basic rocks) are common in Bragança area. Both are associated with Cambisols in gentle slopes and Regosols in colluvial areas. Alisols occur on sedimentary deposits. Fluvisols cover narrow alluvial valleys.

Fallow - Winter Cereal is a very common crop rotation (almost 30 % of Bragança area). Cereal is Wheat (or Rye in the poorer soils) and Fallows are tilled twice in the year. Other land use types are (% of the area):

"Mato", Mediterranean shrubs (28 %);
Pinus *and* Quercus *forests (9 % each);*
Castanea *stands and Permanent Pastures (6 % each).*

2. Conditions prior to measurements

At the time of measurements (March 1996), the area was very much affected by linear erosion features (rills and gullies), mainly found in cultivated fields.

Heavy rainfalls occurred during the late Autumn - early Winter period. By the end of January 1996, the cumulative Precipitation since September (wet season) was twice as that of the average year (924mm against 446mm). Maximum daily Precipitation recorded was 61mm.

Most probably, erosive events generating incisions all over the area occurred between December 22, 1995 and January 9, 1996. This was confirmed by local farmers. Also maximum daily precipitation (January 7) and highest peak discharge (January 8) in Bragança, were recorded in that period.Cereal fields, sown from early November to early December 1995, were still poorly covered at that time.

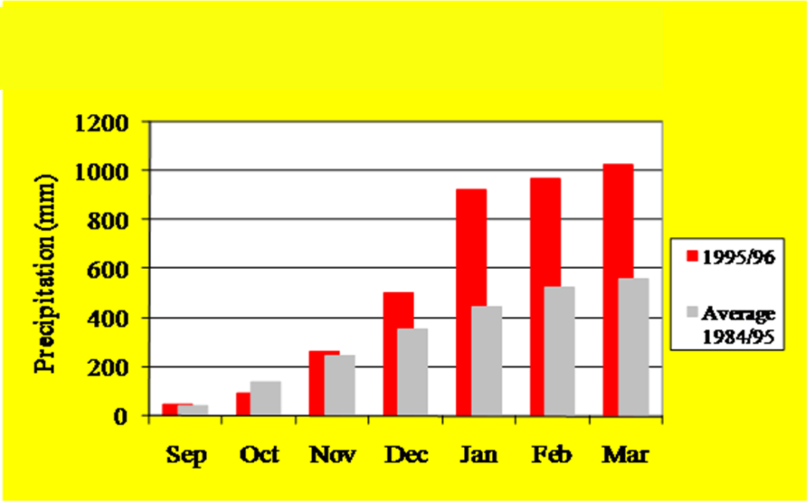

Figure 3: *Precipitation accumulated since summer dry period at Bragança: year of severe gullying compared with the average year.*

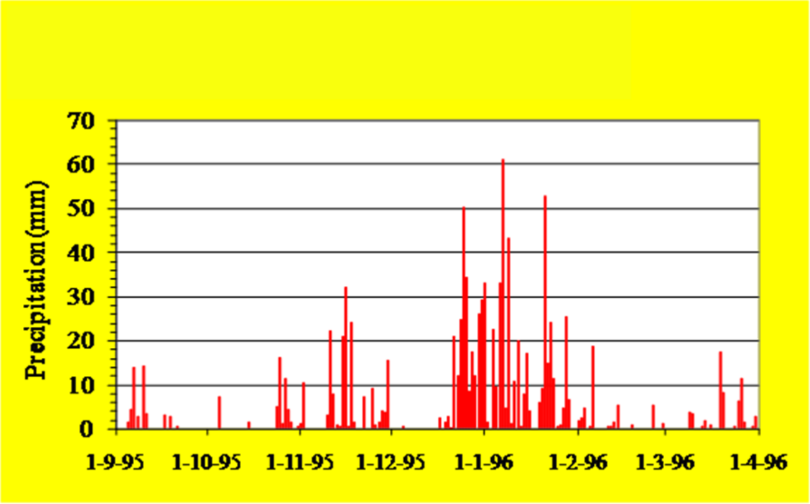

Figure 4: *Daily Precipitation through Fall and Winter in the year of severe gullying in Bragança area.*

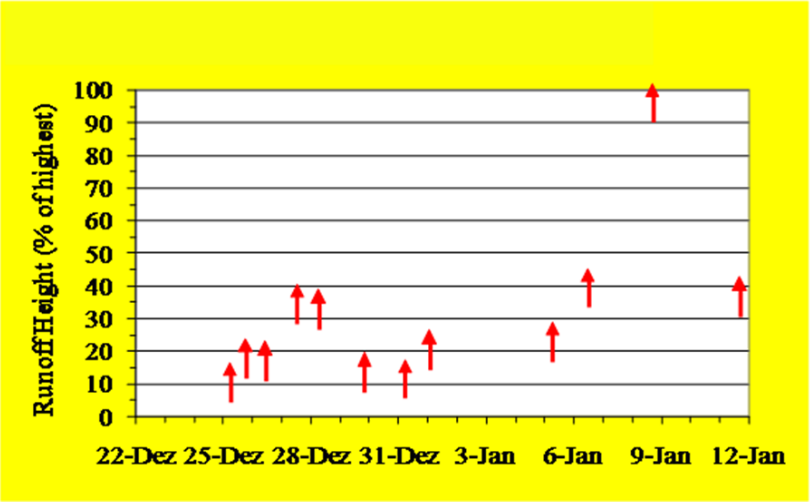

Figure 5: *The limnigraph peaks in a stream in Bragança, during the period of heavier rainfalls*

3. Field work

Sites were selected among the most affected by linear erosion, after a reconaissance survey when rainfalls ceased in the area. Selected catchments have planar or hollowed surface shapes and either convergent (draining to a main gully) or parallel incisions networks. Contour-tillage was evident in all selected fields. Catchments area range from 0.5ha to 4ha and average slope gradients from 10 to 20%.

Catchment area and geometry were assessed stepping upstream along the main gully axis (or a reference direction), stopping at regular distances (10m intervals) and stepping again in perpendicular direction, along a transect up to catchment divides. Therefore, catchments were divided in rectangular trapezoidal areas and their sizes measured by stepping. At each stopping point slope was measured with a clinometer, towards the catchment outlet (thalweg slope) and towards the divides (transect slope). Catchment divides were visually determined in the field, taking into account also micro-topographical features affecting runoff paths, such as tillage ridges or tractor tyre tracks.

Along the transects all incisions (rills and gullies) were identified and their cross-sectional areas estimated, measuring width and depth of incisions

and visually assessing cross-section shape (semicircular, triangular or rectangular). Eroded volumes were estimated by integration of cross-sectional areas along the incisions' axis. Gully erosion volumes were estimated from incision volumes corresponding to cross-sectional areas higher than 900cm2

(1ft2 arbitrarily taken as gully lower size limit). Total eroded volumes correspond to the volume of all measured incisions.

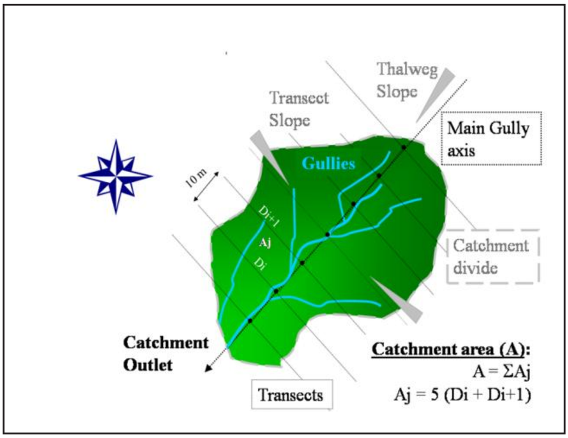

Figure 6: *Field measurements for estimating catchment geometry.*

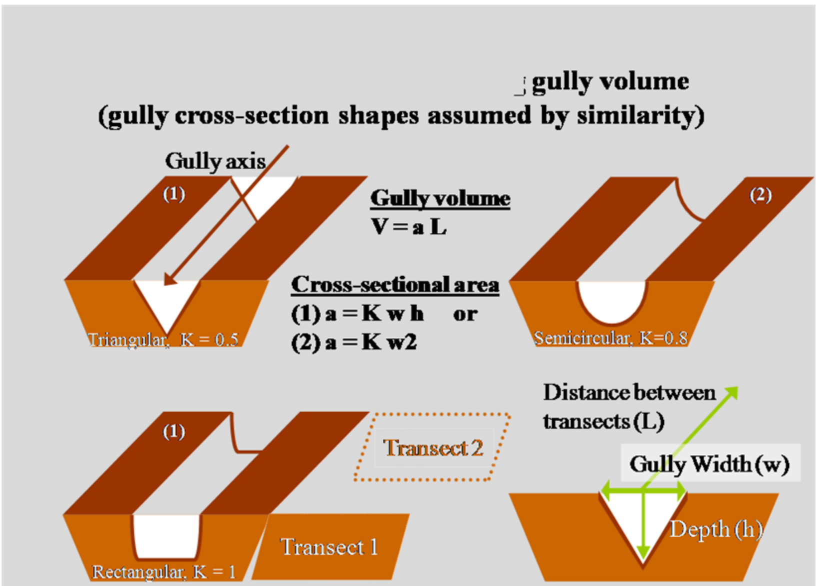

Figure 7: *Field measurements for estimating gully volumes.*

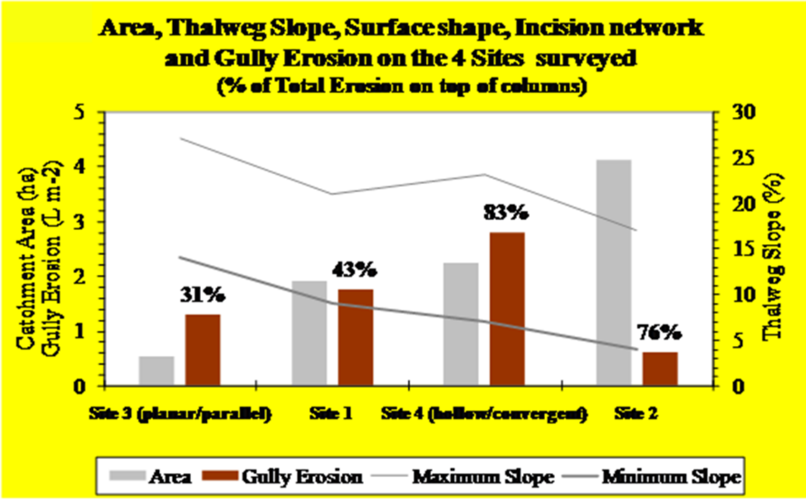

Figure 8: *Catchment characteristics and gully volumes estimated.*

Results and discussion

Results show erosion volumes ranging from 6 to 28 m3 ha-1 in a single season. These are far higher values than those observed under interrill erosion conditions, as annual average interrill erosion rates measured at plot scale in the region are lower than 0.5 ton ha-1. Values found are also 5 to 6 times higher than annual gully erosion rates estimated for Alentejo, Southern Portugal (Vandaele et al., 1996).

Contributions of gully erosion to total erosion ranged from 31 to 83%, falling below values obtained for Southern Portugal (81 to 84%, Vandaele et al., 1996). Total erosion in the paper mentioned included also interrill erosion rates, which were not accounted for in results being presented. The contribution of gully erosion to total erosion tends to increase with the increase of catchment size and with the decrease of catchment slope.

Previous studies conducted in Bragança area (Vandekerckhove et al., 1998) showed that gully initiation depended to some extent on topographical thresholds, such as local slope and catchment area upslope the initiation cross-section. A slope-area (S – A) relationship was derived from measurements in 50 catchments ($S = 0.102\ A^{0.226}$, S in m m-1 and A in ha). Hence, for a given slope, the Minimum Catchment Area for Gully Initiation can be calculated. Catchment area exceeding this critical value should relate with gully extension and, therefore, with gully eroded volumes. Applying the S – A relationship with the 4 catchments "average" slope (average of maximum and minimum thalweg slopes) a Minimum Catchment Area for Gully Initiation was obtained for each site. The difference between catchment area and that value is Catchment Area Exceeding Minimum for Incision. As catchment area is a surrogate of erosive overland flow concentration, this index represents the area contributing to gully extension. Actually, gully eroded volumes, expressed in % of total erosion, are proportional to the square root of Exceeding Area, suggesting that gully extension is related to a linear topographical feature. Yet, the relationship obtained is not statistically significant due to the small sample size (r = 0.862, N = 4, P = 0,138).

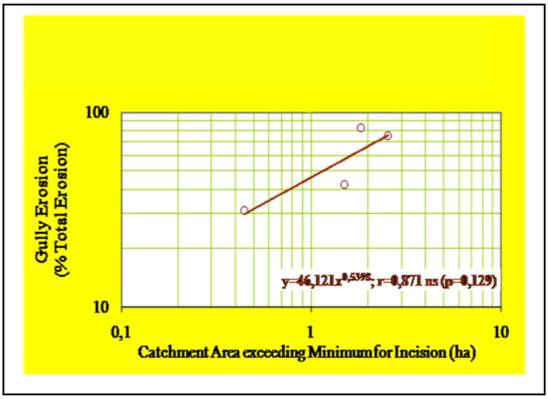

***Figure 9**: Gully erosion (% of total erosion) as related to catchment area exceeding minimum for incision (based on thalweg slope and slope-area relationship).*

Conclusions

These results highlight the regional importance of gully erosion. The combination of low crop cover status with heavy rainfalls allowed the concentration of erosive overland flow, generating linear erosion features all over the Bragança area. Results address the attention to the need of conservation measures specifically coping with this problem.

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Extraction of biomass from forest soils - the main aspects to take into account to prevent soil degradation

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Introduction

The use of low grade timber as a source of energy or raw material for the timber transformation industry is currently being considered in different regions of Spain and other parts of Europe. In addition to the establishment of energy plantations, another possibility is exploitation of the logging residues that remain in plantations after final cutting. This practice could increase the profitability of forest land, and given that in many cases the presence of logging residues increases the risk of fire and spread of disease, it may also help in management of forest stands.

The increasing interest in bioenergy, along with other environmental aspects (accumulation of C, nutrient cycling) has led to the development of allometric equations for the quantification of arboreal biomass (for example; Balboa, 2005; Montero et al., 2006; Bravo et al., 2007). Such equations, which relate the weight of each arboreal fraction to tree variables that are easy to measure in the field, have enabled quantification of the arboreal biomass in some regions and thus estimation of the potential of this resource as a source of energy.

However, before logging residues are removed, their function in protecting the soil should be considered. Many tree stands are established on steep slopes, on nutrient-poor soil, and therefore the removal of biomass may favour erosion and deterioration of the nutritional status of the forest systems. Indiscriminate exploitation may affect the soil organic matter content. Information about the availability of the resource and data that will enable the elaboration of criteria to ensure sustainable exploitation of this resource are clearly required. Furthermore, with appropriate planning this may also provide an opportunity to obtain some environmental benefits, such as C capture.

According to the *Instituto para la Diversificación y el Ahorro de* Energía, *IDEA*, (Institute for the Diversification and Storage of Energy), the conditions in the north of the Iberian Peninsula, in particular in Galicia, are optimal for the generation of energy from forest biomass. However, some limitations, such as

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steep slopes and nutritional deficiencies make good planning necessary to ensure sustainable exploitation of this resource. Some measures that may contribute to this objective are discussed, in light of the results of different studies carried out in the region.

Soil compaction

Logging residues together with the humus layer provide an effective buffer against the weight of heavy machinery used in felling operations and in the preparation of the land for the next rotation. Removal of the remains therefore exposes the soil directly to the weight of the machinery. Under such conditions the soils, especially fine-texture soils are easily compacted. In addition, the impact of raindrops on the unprotected soil favours the development of surface crusts on the soil (Mwendera and Reyen, 1994).

The data obtained in plantations in northern Spain show increases in the apparent density of up to 1.5 g cm^{-3} in land where arboreal biomass has been extracted and heavy machinery used (Figure 1; Merino et al., 1998). The reduction in the pore space produced in these soils is sufficient to prevent root elongation (Froehlich et al., 1986; Skinner et al., 1989), thereby affecting growth of the next rotation and also delaying the establishment of scrub and herbaceous vegetation (Figure 2), in addition to affecting run-off and erosion, which will be discussed further below. It is important to emphasize that recovery of such soils is a slow process (Figure 1), due to the difficulty experienced by the scrub plants to become established in compacted soil (Rab, 1996; Froehlich et al., 1986; Edeso et al., 1999).

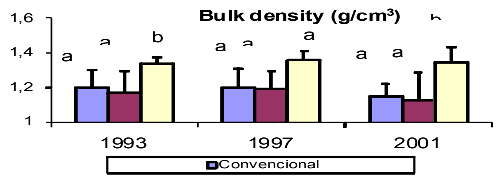

Figure 1: *In clay soils under moist conditions, the removal of all of the arborealbiomass and the introduction of heavy machinery may lead to significant compaction of the soil. Recovery of soil porosity is a slow process (Merino et al., 2004).*

***Figure 2**: Soil compaction resulting from the introduction of heavy machinery and the impact of raindrops limit growth of forest plantations.*

Soil erosion and water quality

Soil erosion is of special interest in steeply sloping forest land, where shallow soils may be considered as a non-renewable resource. Erosion affects the forest system through loss of depth and fertility of the soil, which have repercussions on productivity. This process also affects aquatic systems linked to forest catchments, by reducing regulation of the water flow and increasing the turbidity and concentration of solutes in the water.

Although forest systems offer the best protection against soil erosion, in intensive forest exploitations, soil loss greatly depends on the practices carried out after felling. If the logging residues and the humus layer are left on site, the run-off will only increase slightly and the rate of erosion will be low. If on the contrary, large amounts of the remains are removed from steeply sloping areas, the degree of erosion may be significant (MILLER et al., 1988). In this respect, different studies carried out in Spain show that the total removal of forest biomass, as a result of fire (Benito et al., 1991; Fernández et al., 2006) or intensive land preparation (Olarieta et al., 1999; Edeso et al. 1999; Fernández et al., 2004) causes large increases in run-off and erosion. The effect of the indiscriminate extraction of biomass on erosion is particularly important in clay soils, in which low infiltration rates favour run-off (Figure 3).

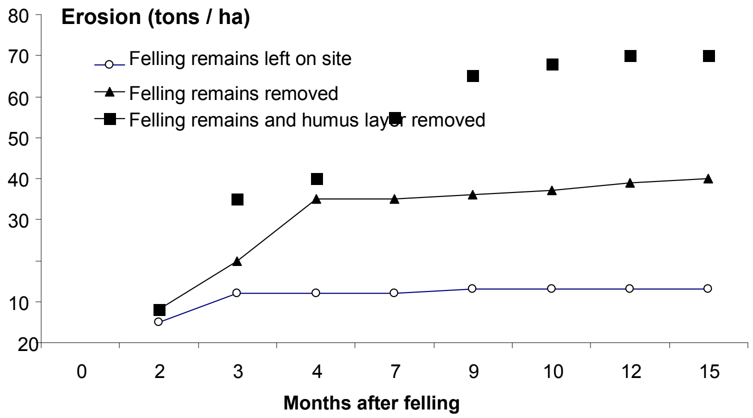

Figure 3*: If logging residues are left on site, low rates of erosion are maintained, even after clear cutting. Rates of erosion may be high in steeply sloping land where logging residues are removed (Edeso et al., 1999).*

Figure 4*: If the biomass is removed some time later, when the material is dry, most of the leaves/needles remain on site and protect the soil from erosion.*

Clearly, run-off and erosion will increase with the amounts of logging residues removed. One way to avoid this in steeply sloping areas is to remove only the thickest branches. If the logging residues are left to dry on the land before being removed, a large part of the small branches and the leaves/needles will remain (Figure 4). In this type of exploitation, disturbance of the humus layer by heavy machinery will be minimal. A study in which selective removal of thick branches was carried out in an area of slope 35 % (Balboa, 2005) showed that this practice slightly increased the generation of surface run-off (obviously the removal of the material reduced the water capture), without increasing erosion (Figure 5).

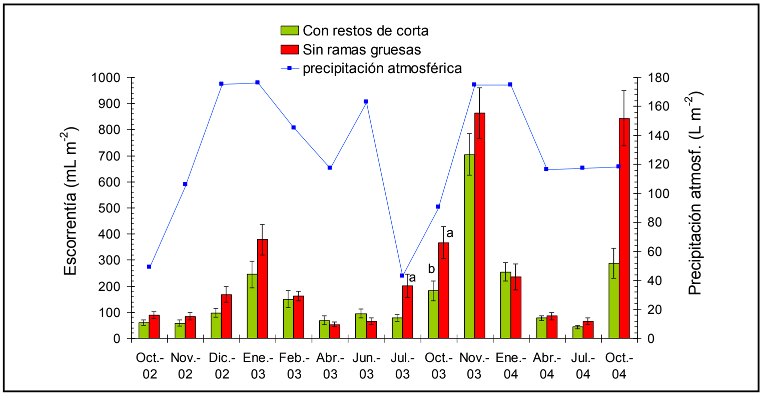

Figure 5*: In stands situated on moderate slopes, the selective removal of the thickest branches to leave the finest branches and leaves/needles leads to a relatively small increase in run-off. Note that the run-off is low in both plots, as the humus layer is retained in both (Balboa, 2005).*

Soil fertility

The tree fractions that are richest in nutrients are the fine branches, leaves and in the case of eucalyptus, the bark. This means that, despite the lower weight with respect to the total biomass (in intensive plantations in northern Spain, between 15 and 35 %; Balboa, 2005; Montero et al., 2006), the logging residues accumulate a large portion of the nutrients that the stand has assimilated during the rotation (Fisher and Binkley, 2000). If this material is deposited on the soil, the nutrients released during its decomposition may be available to the next rotation. Removal of the material, on the other hand, implies the extraction of a substantial amount of nutrients from the system.

In fact, exploitation of plantations may involve the extraction of P, K, Ca and Mg in quantities comparable to the soil reserves. The increase in the amounts of nutrients removed from the system in some cases may affect the nutrient status of the system (Fölster and Khanna, 1997; Olsson et al., 2000; Dambrine et al., 2000; Merino et al., 2005). This is especially important in northern Spain, where intensive forest plantations are often deficient in nutrients, particularly P, Mg and Ca (Romanyà and Vallejo, 1996; Sánchez-Rodríguez et al., 2002; Merino et al. 2003).

Intensive exploitation of eucalyptus is clearly unfavourable in this respect. In plantations of *Eucalyptus globulus* in the north of Spain, conventional exploitation of these trees (for timber and bark) involves the extraction, every 18 years, of more than 80 % of the quantities available in the soil (Merino et al., 2005). More Ca is extracted from these systems than the amounts supplied by natural processes (rainfall, mineral weathering) (Fig. 5). In the case of pine plantations, the situation is not as serious, although the amounts of some nutrients extracted are close to the amounts that the system can replace via natural processes (Merino et al., 2005; Rodríguez-Soalleiro et al., 2007).

Phosphorus deserves special mention for several reasons. In acid and alkaline soils it is one of the most limiting elements for plant production given that the most readily available forms of P (HPO_4^{-2} and $H_2PO_4^-$) only occur within pH 4.8 to 6.2. Furthermore, soil systems have a low capacity to replace this element, given the extremely low quantities provided by mineral weathering and atmospheric precipitation. The main means of replacement is therefore internal, via the decomposition of plant remains. In this respect, most of the P extracted by the exploitation involves a net loss of the element.

However, the deficiencies caused by extraction of nutrients can be overcome by the application of a suitable fertilizer. This need is recognised in the two systems of Certification of Sustainable Forest Management (PEFC and FSC). Fertilization is easily carried out in plantations designed for mechanised labour, i.e. with low or moderate slopes and with pathways to allow movement of vehicles. In plantations not designed in this way, the application of fertilizers is more complicated because in many sites the topography does not allow the use of heavy machinery. Nonetheless it must be pointed out that the amount of fertilizers required to replace nutrients is much less than required for agricultural soils, and many forest managers opt to use light machinery or manual application for distributing mineral fertilizers.

One alternative to conventional fertilizers is the use of certain waste products that contain low levels of heavy metals or toxic substances. In stands developed on acid soils, ash generated from biomass plants may be used as this product is rich in K, Mg, Ca and P, supply of which favours growth of forest stands (Figure 6, Solla-Gullón et al., 2006; Omil, 2007). An example of another waste product that can be used in these plantations is the sludge generated by the waste water treatment plants used in the dairy industry, and characterized by extremely low levels of heavy metals (Omil et al., 2007). Input of organic materials of this type not only contributes to the replacement of nutrients, but also to maintaining the levels of organic matter, as will be discussed further below.

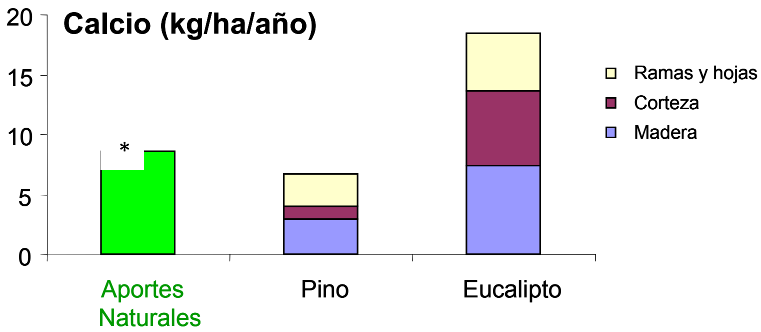

Figure 6*: The removal of nutrients by exploitation of rapidly growing species may exceed the inputs by natural means, such as weathering of minerals or atmospheric inputs. In the case of eucalyptus, the large accumulation of Ca in tree parts, especially the bark, should also be taken into account (Adapted from Merino et al., 2005).*

** Data from Dambrine et al. (2000)*

Soil moisture content and temperature

The layer of logging residues and the humus layer together exert a mulching effect, thereby maintaining the soil moisture and buffering the temperature of the soil. This combined layer reduces losses by evaporation in two ways. On one hand it reduces the growth of accompanying vegetation and thus the loss of water by transpiration. On the other hand, it forms a highly porous layer with a low capacity for capillary rise. Land where logging residues are removed tends to be less moist and the drought period is prolonged (Figure 7; Pérez-Batallón et al., 2001). In soils in zones with hydric limitations, the selective removal of logging residues may reduce these negative effects.

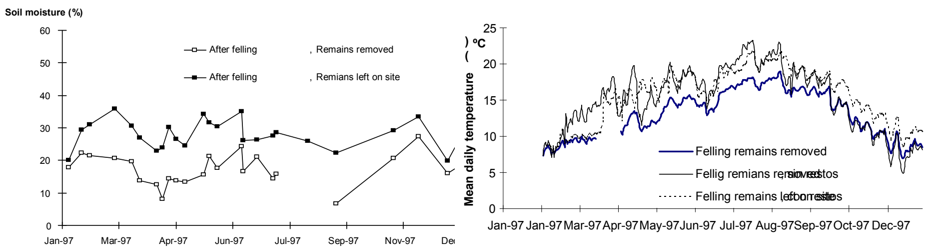

***Figure 7**: The layer of logging residues forms a mulch that is effective at preventing evaporation and increased temperatures in the uppermost layers of the soil. When the logging residues are removed the drought period is prolonged and the soil temperature increases (Pérez-Batallón et al., 2001), with the consequent negative effects on survival of the next rotation.*

Likewise, the daily temperature fluctuations in the soil increase considerably after felling (due to increased direct radiation reaching the soil and loss of heat during the night). However, the logging residues are effective buffers of thermal fluctuations (Figure 8) and increase the survival of the new plantation. Again, the selective removal of logging residues buffers these effects.

Organic matter content

Logging residues accumulate 20-35 % of the carbon content of a tree, and therefore they can contribute to maintaining the levels of organic matter in the soil. This is especially significant because the soil organic matter is not only the most important short-term reserve of some nutrients, but it is also the soil component that is most involved in maintaining plant water reserves and in protection against soil erosion.

It must also be considered that increases in soil temperature following felling tend to favour soil microbial activity, although this effect also depends on soil moisture. In stands where the logging residues are removed, the lower inputs of plant remains along with the higher soil microbial activity will lead to a gradual loss of soil organic matter in the intermediate term. In fact, some studies have shown a reduction in the soil organic matter content in intensively managed plantations (Turner and Lambert, 2000). The loss of soil organic matter as a result of the repeated removal of biomass is not consistent with the Kyoto Protocol, in which compensation by carbon capture in soils is proposed.

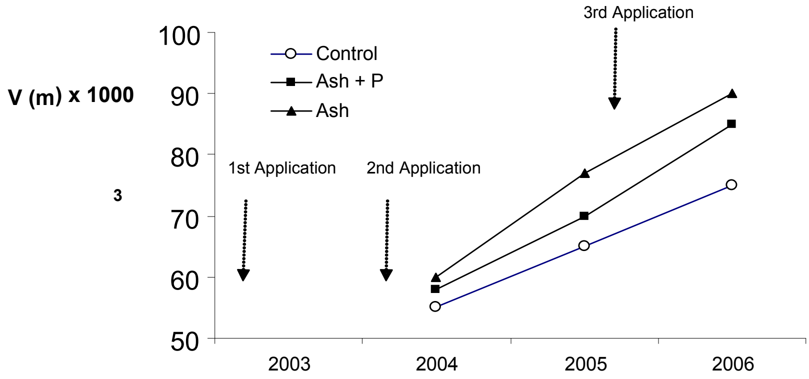

Figure 8*: Forest plantations destined for biomass production can be fertilized with ash generated in biomass plants, which is rich in nutrients. This practice not only improves the yield of the stand and its nutritional status, but also contributes to environmentally sound management of the waste product. The data in the graph correspond to a Pinus radiata plantation to which ash from bioenergy plants was added at repeated intervals, at doses of 4.5 t/ha (Omil, 2007).*

This aspect may not only affect the organic matter content, but also the diversity of soil microorganisms, which may also affect certain inherent biological processes. Amongst these, forest soils play an important role as consumers of atmospheric CH_4 (Mosier et al., 1991), whose potential is considerably reduced as organic matter is lost (Steudler et al., 1989).

The input of ash or other clean organic waste products may partly mitigate the loss of soil organic matter, not only through the direct input of organic C (which in the case of ash is in the form of carbon and therefore much more resistant to decomposition) but also through the positive effects on plant production, thereby increasing the amounts of leaf litter and fine roots (Santalla, thesis in prep.).

As regards C capture, one important aspect is the establishment of forest plantations destined for timber production, energy purposes or both, in marginal agricultural soils. In these situations, C is captured in both the biomass and in the soil, which may be particularly important in dense plantations. This leads to an improvement in the conditions of these soils, which usually contain low levels of organic matter. In this respect, the benefits have been estimated as approximately 0.1-0.5 tm C/ha/year (Romanyà et al., 2000; Paul et al., 2002; Pérez-Cruzado et al., 2007). However, this may also contribute to climate change (Liski et al., 2002; Bravo et al., 2007). In this respect, recent data show that forest systems in Europe are currently storing between 9 and 12% of the anthropogenic emissions of CO_2, whereas storage of C in soils currently involves 3% of these emissions (Liski et al., 2002). The increase in forested area also contributes to recovering the capacity of soils to consume atmospheric CH_4 (Figure 9).

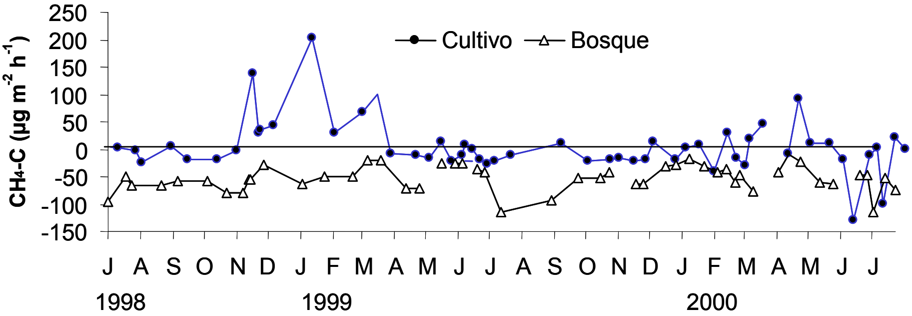

Figure 9*: Agricultural soils have lost their ability to absorb CH4. Reforestation of agricultural land may result in soils recovering this capacity, which helps maintain atmospheric CH_4 in equilibrium. The figure shows the CH_4 flows in an agricultural soil compared with those in another adjacent soil reforested 40 years earlier (Merino et al., 2004).*

Conclusions

The need to plan silvicultural practices to prevent damaging effects in soils

The continual extraction of biomass in forest systems may cause different types of soil degradation such as compaction, erosion, loss of nutrients and loss of organic matter. Most of these problems can be prevented or reduced by prior planning that identifies forest land that is suitable for this practice. In addition, prior assessment of the possible effects on soils and water are essential, along with analysis of the most appropriate silvicultural practices. If these aspects are considered carefully, biomass exploitation may also provide an opportunity to obtain a series of environmental benefits, such as the generation of renewable energy and the recapture of C in biomass and soils.

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The role of forests in mitigating climate change

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Abstract

Of the five major greenhouse gases (carbon dioxide, methane, nitrous oxide, ozone and chloroflurocarbons) only the chloroflourocarbons (CFC) are of exclusively industrial origin. A large part of the increases in CO_2, CH_4 and N_2O originate from biological processes in terrestrial systems, and cause approximately half of the so-called greenhouse effect. The human activity in terrestrial ecosystems that has contributed most to increasing the concentrations of greenhouse gases is the transformation of natural ecosystems to agricultural land. This has led to emissions of CO_2, CH_4 and N_2O from the burning of biomass, and from the soil itself. Terrestrial ecosystems will also be affected by global climate change, with the most likely effects including increased growth rate of plants, a higher incidence of diseases and fire, and loss of soil organic matter. Management of terrestrial ecosystems may temporarily buffer the concentrations of greenhouse gases in the atmosphere. The general strategies for mitigating these effects are the conservation of natural ecosystems (forests, wetlands and peat bogs), recovery of forest land and the application of different silvicultural and agronomic techniques.

Increase in GHG and the effect on global warming Carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), chlorofluorocarbons (CFC) and ozone (O_3) - collectively known as greenhouse gases (GHG) - allow short-wave solar radiation to enter the earth's atmosphere, but trap much of the long-wave radiation released from the earth's surface. This influences the temperature of the planet, as well as the types of climates. Relatively small increases in the concentrations of these gases may therefore have serious repercussions on the environment.

The current concentration of atmospheric CO_2 (367 ppmv) is 31% higher than before the industrial revolution. However, the increase in the amount of methane (CH_4) has been much greater, as this gas has increased by 151 % (the

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current atmospheric concentration is 1745 ppbv). The amount of N_2O, which is also implicated in the deterioration of the ozone layer, has increased by 7 % (the current concentration is 314 ppbv). There is now sufficient evidence to show that the increases in the amounts of these gases in the atmosphere during the past century are altering the climatological conditions on the planet.

Table 1. Characteristics of the five principal greenhouse gases (IPCC, 2001).

	Carbon dioxide (CO_2)	Methane (CH_4)	Nitrous oxide (N_2O)	Chlorofluorcarbonos (CFC)	Ozone (O_3)
Main natural sources	Release from soil and oceans	Wet zones, enteric fermentation (stomachs of non domesticated ruminants)	Release from soils and oceans	None	Transport from trophosphere, photochemical production in the trophosphere
Main artificial sources	Combustion of fossil fules, transfomration of forest soils to agricultural soils, cement manufacturing	Rice fields, enteric fermentation (domestic animals), biomass combustion, escapes of natural gas	Fertilized soils, fossil fuel combustion, biomass burning	Refrigerants, propellants	Reactions with NO_2, CH_4 and hydrocarbons
Current atmospheric concentration (parts per billion by volume)	367,000	1720	310	CFC-11: 0.28 CFC-12: 0.48 Others: 0.005-0.12	20-100
Preindustrial atmospheric concentration (parts per billion by volume)	280,000	790	280-290	0	10
Half-life in				CFC-11: 65 years	

the atmosphere	50-200 years	10 years	120-150 years	CFC-12: 120 years Others: 0-400 years	Hours-days
Potential warming relative to CO_2	1	21	310	CFC-11: 3970 CFC-12: 5750 Others: 3710-5440	Depends on altitude
Relative contribution to greenhouse effect	60 %	15 %	5 %	12%	8 %

Of the five greenhouse gases, only the CFC are of exclusively industrial origin (Table 1). The increases in CO_2, CH_4 and N_2O largely originate in terrestrial ecosystems, from the activities of plants and animals or are related to soil biological processes. Half of the emissions of CO_2 and most of the emissions of CH_4 and N_2O are caused by the intense anthropogenic disturbance of terrestrial ecosystems.

However, forest and agricultural ecosystems may themselves be affected by changes to the climate and by the higher atmospheric concentrations of these gases. Thus, a higher incidence of forest fires and desertification is predicted in Spain, and will particularly affect the driest Mediterranean regions. A higher incidence of pests and diseases are also expected, as well as physiological changes in plants (Moreno Rodríguez et al., 2005).

Great efforts are currently being made to stabilize the concentration of atmospheric CO_2 at levels of between 450 and 650 ppm. Measures aimed at reducing the industrial and urban emissions and the capacity of aquatic and terrestrial ecosystems to capture carbon is also being exploited. Many of the strategies consider the application of agroforestal management methods as a way of fixing atmospheric C in plant biomass and soil. These sinks are therefore alternatives to the trading of carbon quotas within the mechanisms proposed in the United Nations Framework Convention on climate change and the Kyoto Protocol (article 3.4; www.unfcc.de). Along the same line, the Common Agricultural Policy (CAP) has promoted different practices to improve soil conservation and carbon capture. Likewise, the Spanish Forest Plan has included carbon fixation as one of its objectives.

This chapter includes a brief description of the role of terrestrial ecosystems and agroforestal management in the composition of the atmosphere and climate change. Some of the general strategies aimed at mitigating climate change by agroforestal management will also be discussed. The text provides a brief vision of the most relevant aspects.

Global flow of GHG and distribution of C in terrestrial ecosystems

Carbon is stored in 5 large compartments in the planet (Figure 1). The largest reserve of C is in the oceans, where 38000 Pg of C (1Pg C = 10^{15} g C) are accumulated. Geological reserves constitute the second largest carbon store, with 5000 Pg of C, of which 4000 Pg are accumulated in the form of coal. The third most important compartment is the soil, with 2300 Pg, in which C is found in two components, the organic matter (67 %) and in inorganic compounds, such as carbonates (33 %). The next most important reserve is the atmosphere, where there are 760 Pg of C accumulated at present. Finally, living organisms contain a total of 560 Pg of C.

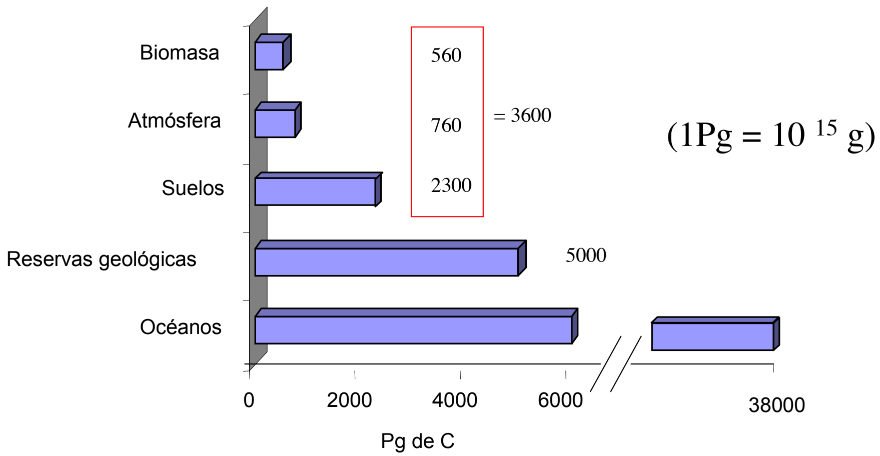

***Figure 1**: Carbon stores in the planet earth*

These large compartments are not isolated from each other, but are interconnected. Human activities have a direct effect on the flow of C between these compartments, thereby affecting the distribution of C in each. As well as natural emissions from the respiration of organisms and the decomposition of waste, which are regulated by photosynthesis and the exchange of gases in the oceans, emissions derived from the combustion of fossil fuels and those derived from land use must also be considered.

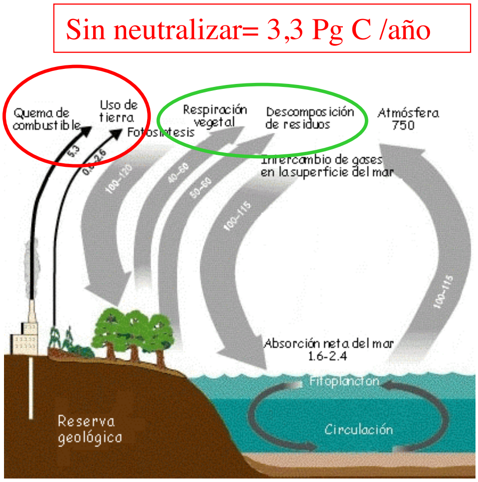

***Figure 2**: Carbon flows among compartments (Non neutralized= 3.3 Pg C/year.)*

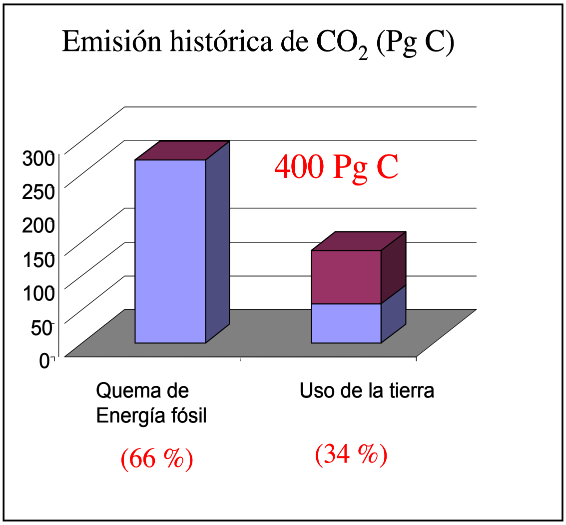

***Figure 3**: Anthopogenic emissions of CO_2 since 1975. (Emisión histórica de CO2, Fossil fuel combustion, Land Use).*

The emissions of C as a result of the combustion of fossil fuels since the industrial revolution, are estimated at 270 PgC, whereas transformation of forest land to agricultural land has involved the emission of 136 PgC to the atmosphere (Lal, 2004), from both plant biomass (58 Pg C) and soil (78 Pg C) (Figure 3). Such emissions are not totally consumed by natural mechanisms. Calculations show that of the 8 Pg C/year that are emitted at present by anthropogenic sources, only 4.7 Pg C/year are reabsorbed by oceans and terrestrial systems (IPCC, 2001). The amount of C accumulated in the atmosphere is currently increasing at a rate of 3.3 Pg C/year.

Distribution of C in terrestrial ecosystems

Some 40 % of the total C contained in terrestrial ecosystems is found in soils and forest biomass. Tree vegetation includes 70 % of all the C accumulated in the vegetation on the planet. Grasslands and agricultural systems accumulate 34 and 17 % of the C, respectively (Figure 4).

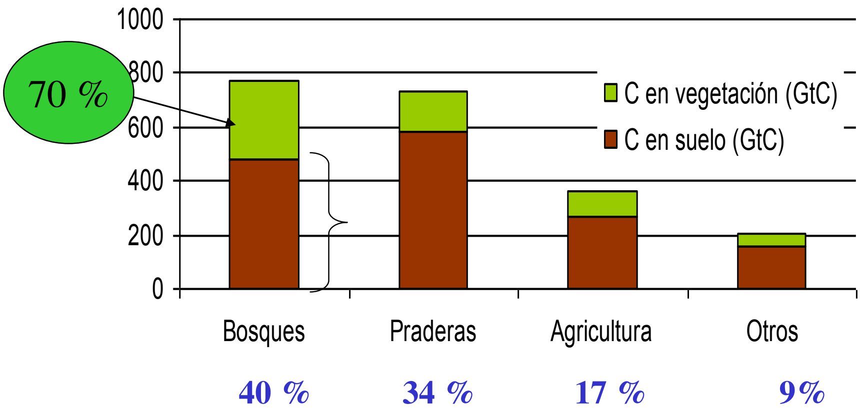

***Figure 4**: Distribution of carbon in terrestrial ecosystems.*

Tropical and boreal forests accumulate the largest quantities of C. However, the internal distribution of C is very different in each of these systems. In tropical forests much more C is accumulated in the vegetation than in the soils. In contrast, the soil in forests in temperate and cold areas accumulate much greater quantities than the vegetation. Peat soils or Histosols, which are characteristic of cold zones, accumulate 30 % of the C content of the planet's soils, and therefore play a key role in regulating the composition of the atmosphere.

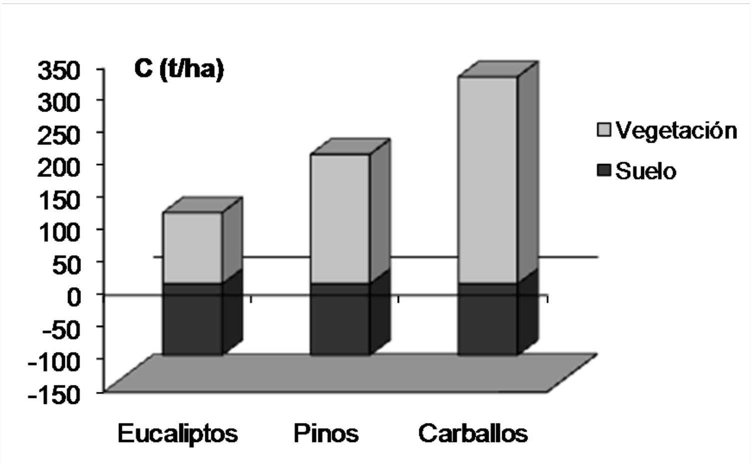

Figure 5*: Accumulation of C in arboreal biomass and soils in plantations of eucalyptus and pines (Merino et al., 2005) and in semi-natural oak forests (Balboa et al., 2005)*

Although in general, forests at intermediate latitudes accumulate lower quantities of C, there are rainy areas within this zone, where production increases considerably and very high quantities of C are stored in both vegetation and soils. This is the case in the forest systems in Galicia, and in general in the Cantabrian Region (Figure 5). Plantations of eucalypts and pines in the conditions prevailing in Galicia accumulate between 100 and 200 t C/ha in biomass, at a fast rate of between 5 and 7 t C/ha/year (Merino et al., 2005). However, a large part of the timber produced in these plantations is transformed into paper or other products of intermediate duration, and thus the C accumulated by these species returns to the atmosphere in a relatively short time. Natural or seminatural forests, such as oak and beech forests may accumulate more C than the previous plantations, often between 200 and 300 t C/ha (Balboa 2005). However, because these species grow slower, the accumulation of C is also slower, and this biomass remains stable for much longer. Forest soils in Galicia store similar amounts of C as stored in the biomass. Thus, C contents of as much as 150 Mg C/ha are common in deep soils.

How much carbon do soils accumulate?

The C content in soils worldwide is about three times higher than the C content in vegetation. Soil organic carbon therefore plays a critical role in maintaining the global balance of C. Furthermore, soil organic matter (SOM) has important effects on the porosity and on reserves of water and nutrients in the soil, and is moreover one of the most important parameters for evaluating the susceptibility of soils to erosion.

The amount of organic matter is primarily determined by environmental aspects, such as climate, topography, vegetation, *etc.*, although silvicultural management is also important.

1) *Histosol* in the *Central Massif*. 2) *Umbrisol* in the *Central Massif* 3) *Cambisol* in Galicia. 4) *Luvisol* in a high terrace beside the river Tormes. 5. Typical *Calcisol* in Levante.

(Photographs: J. F. Gallardo and A. Merino)

The highest contents of organic matter (up to 1 Gg C ha^{-1}; 1 Gg = 10^{9} g) occur in peat soils (*Histosols*, Photo 1), in which the low temperatures and hydric excess slow down organic decomposition. The C contents are also high (up to 200 Mg C ha^{-1}) in *Umbrisols* (Photo 2) in the temperate regions of Northern Spain and in mountainous regions, where the high precipitation and moderate temperatures result in production of large amounts of organic matter. The levels are much lower between 80 and 150 Mg C ha^{-1}, in *Cambisols* (Photo. 3), found extensively throughout Spain. *Luvisols* (Photo 4) dominate in the ancient land of the plains, and are generally associated with semi-arid areas, with low precipitation that limits plant production, unless irrigated. *Calcisols* are common in many semi-arid zones of Spain, especially in Levante and southeastern Spain, where they are found as carbonates (Photo 5).

The effect of agricultural management on climate change

1. Emission and consumption of GHG in terrestrial systems

Figure 6 is a simplified diagram of the flow of gases between terrestrial ecosystems and the atmosphere. Vegetation absorbs atmospheric CO_2 via photosynthesis and releases the gas via respiration. Part of the C accumulated returns to the atmosphere as a result of deforestation or biomass combustion. Terrestrial ecosystems are also involved in the flows of other GHG, such as CH_4 and N_2O. Thus, ruminants produce large amounts of methane, while forest soils absorb CH_4, and thereby contribute to regulating the atmospheric concentration of this gas. Nitrous oxide (N_2O) is also produced in poorly aerated soils, and has increased in recent years due to the intensive use of nitrogenous fertilisers.

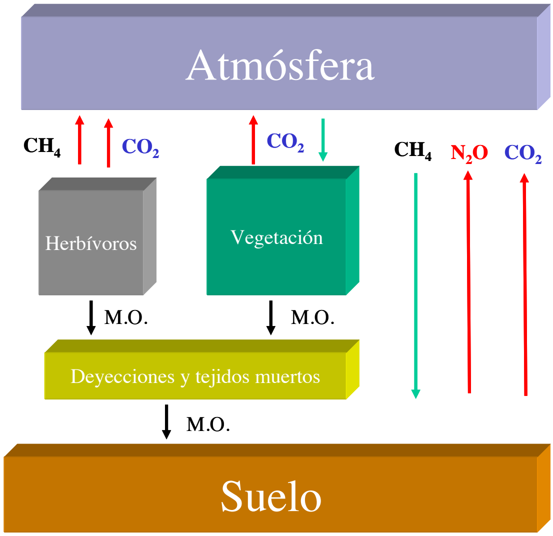

Figure 6: *Flows of organic matter and greenhouse gases in terrestrial ecosystems.*

2. Transformation of agricultural soils to forest soils

The type of human disturbance of ecosystems that has contributed most to increasing GHG is the transformation of natural ecosystems to agricultural land. This type of disturbance has caused a substantial reduction in vegetation, as well as losses of 30-50 % of the C contained in soils. Different analyses (Post and Kwon, 2000) have shown that in the 1980s, approximately 16 Pg C/year were lost in the form of CO_2 as a result of the transformation of forest to agricultural land.

Large emissions of CO_2 from soils are registered when management techniques that increase the rate of mineralization of soil organic matter are applied. For example, when intensive tillage is carried out, or when humid areas are drained before exploitation. Large emissions are also produced during felling, as a result of the increase in soil temperature that occurs (Ouro et al., 2001; Pérez-Batallón et al., 2001; Balboa, 2005). Soil erosion and degradation also considerably increase the release of CO_2 (Martínez-Mena et al., 2002).

Figure 7: *Transformation of forest to agricultural land is the type of human disturbance that causes the highest emissions of CO2 from ecosystems.*

An evaluation of the C content of soils under different types of use in Spain is given by Rodríguez Murillo (2001). In Galicia the mean contents of C in soils suggest C losses of approximately 40 % (Macías et al. 2001a o b?), although these are highly dependent on the posterior management, mainly the inputs of organic manures, the fertilisers applied and the intensity of tillage (Sánchez and Dios, 1995; Verde et al., 2005; Díaz-Raviña et al., 2005), as shown in Figure 8.

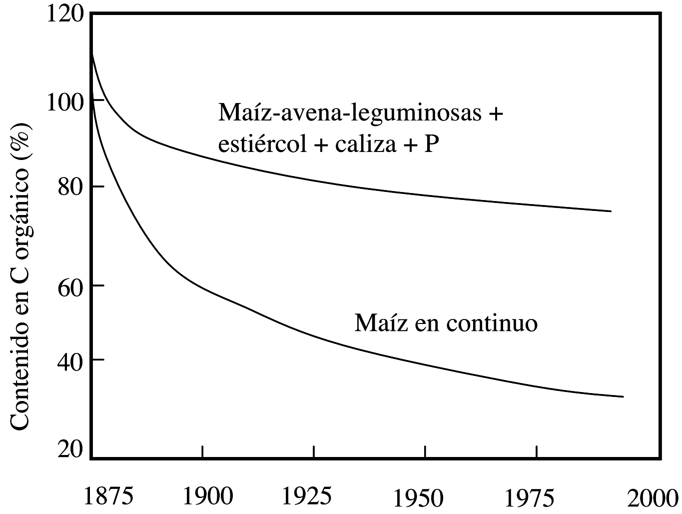

Figure 8*: Changes in the loss of organic matter in a forest soils following its transformation to agricultural land. The loss is ameliorated by the inclusion of grasses and legumes (the remains of which provide organic matter) in the rotation and the application of manure.*

The changes in the forest areas in Europe do not reflect the extent of the problem of deforestation. More than 80% of the forest surface has been lost in the European continent (Table 9). However, with the exception of tropical zones, which at present act as net emitters of CO_2, in recent decades, the transformation of forest land to agricultural land has slowed down, and has even been reversed, owing to the greater availability of electricity, petrol and carbon, which has reduced pressure on the land (IPCC, 2001). Thus in temperate zones, much marginal land has been reforested and at the same time, different conservation measures have been applied to natural forests, which not only help to mitigate climate change but also to preserve biodiversity and the quality of water and soil.

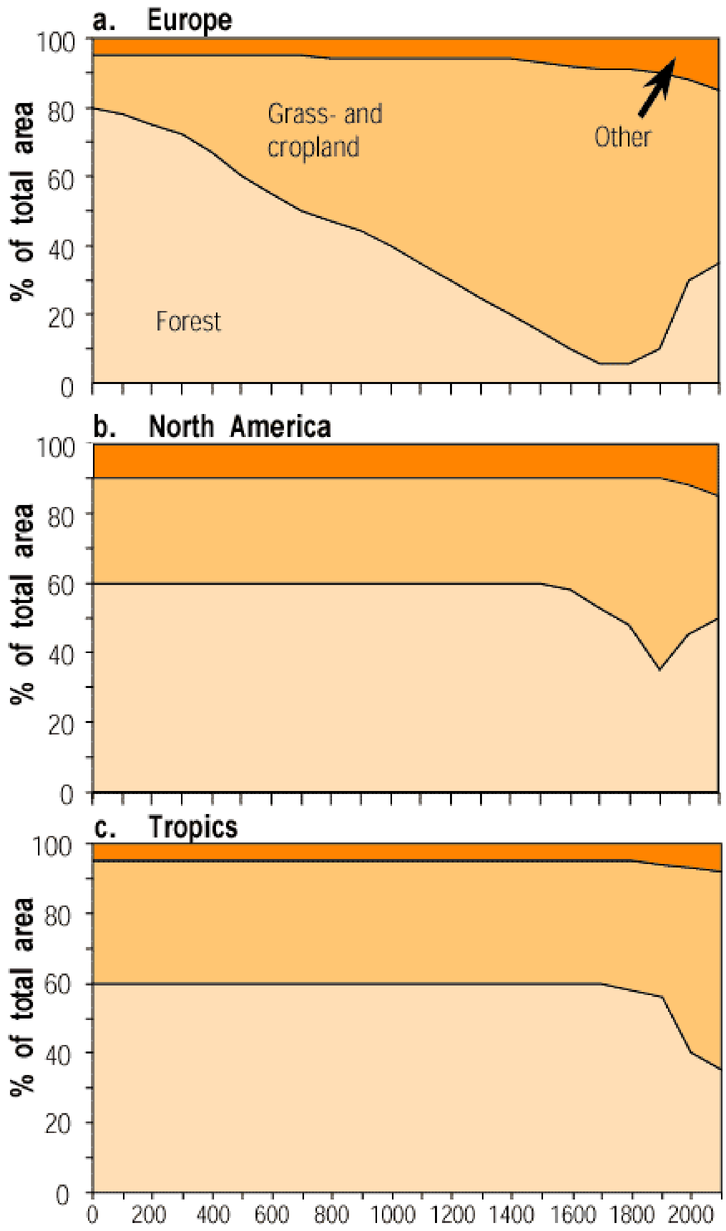

***Figure 9**: Changes in forest and cultivated land.*

3. Intensive management of forest stands

The decomposition of soil organic matter in intensively managed plantations is another important source of CO2. After clear felling, the soils receive direct solar radiation, which increases the soil temperature and therefore microbial activity in the soil, which in turn favours decomposition of organic matter. This process is accelerated where intensive land preparation techniques are applied, including tillage and removal of felling remains. However, it is understood that this loss is partially compensated during the rotation, by inputs from leaf fall.

4. Flows of CH4 and N2O derived from land use

Intensive human disturbance of terrestrial ecosystems has also altered the flows of CH_4. The increase in the areas of land occupied by rice crops, the proliferation of dumps and the greater numbers of ruminant livestock have led to a sharp increase in the emissions of CH_4 to the atmosphere in the last few decades.

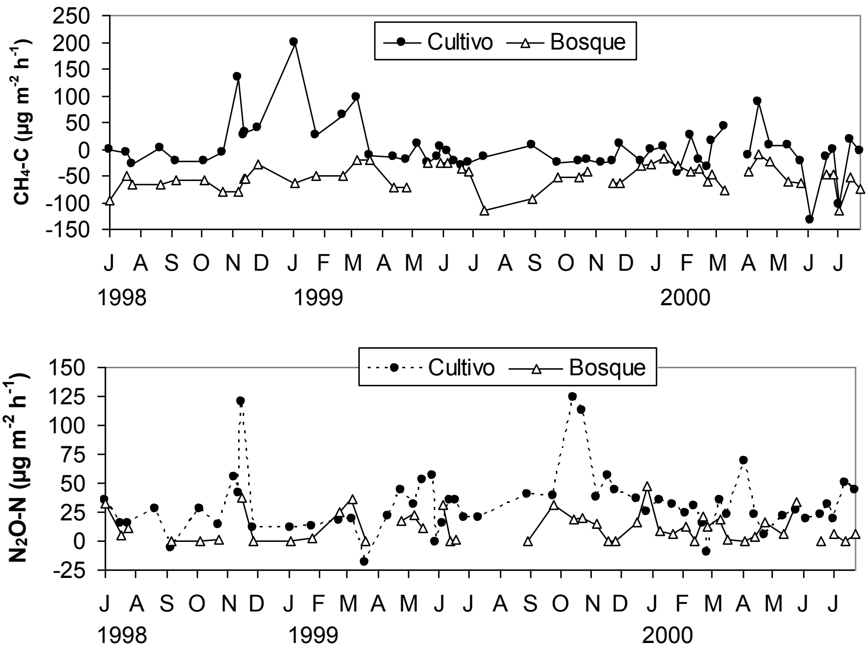

***Figure 10**: Changes in flows of CH_4 and N_2O in two Galician soils (Merino et al., 2004).*

The concentration of atmospheric CH_4 is regulated by microorganisms that live in forest soils that consume the gas (Bouwman, 1990). However, this methanotrophic capacity disappears in agricultural soils owing to changes in the microbial populations and to the lower rate of diffusion due to compaction (Steudler et al., 1989). The capacity of an Galician oak soil to oxidise CH_4 is illustrated in Fig. 10ª , in which it can be seen that the adjacent agricultural soil has lost this capacity and does not only not consume CH_4, but under conditions of high humidity, emits the gas (Merino et al., 2004).

Agricultural soils that receive large inputs of nitrogenous fertilizers are the main source of N_2O emitted to the atmosphere. Slurry pits and water treatment plants also emit large quantities of N_2O. Under conditions of high humidity in agricultural soils, the processes of nitrification and denitrification are favoured, with the consequent formation of N_2O (Bouwman, 1990; Estavillo et al., 2002). Fig 10 b shows the high emissions produced in a Galician agricultural soil coinciding with inputs of nitrogenous fertilizer (Merino et al., 2004).

The agricultural exploitation of peat soils is a special case. These soils retain a large amount of C, and under normal conditions, emit CH_4. When these soils are drained for agricultural exploitation, the emission of CH_4 ceases, but the emission of huge quantities of CO_2 and N_2O to the atmosphere is stimulated.

Impact of climate change on the dynamics of greenhouse gases in terrestrial systems

The previous information shows how human disturbance of terrestrial ecosystems contributes to climate change. Climate change has important repercussions on these ecosystems, leading to changes in the development and distribution of plants, as well as the organic matter content of soils.

One important aspect of this is the plants' response to higher concentrations of CO_2 in the atmosphere. The increase in the atmospheric concentration of CO_2 increases the rate of photosynthesis and hydric efficacy, thereby increasing the growth of many plants (especially type C3). This leads to an increase in biomass, which may in turn lead to higher production of soil organic matter. Obviously if nutrients and water are limited, this effect will be curbed to some extent. However, although the response of an individual tree to increased concentrations of CO_2 will generally be positive, other factors may also be involved, such as phenology, the chemical composition of the leaves and their decomposition (especially the C/N ratio), which may modify the overall response. At the same time, an increase in temperature may have indirect effects on ecosystems, such as greater incidence of damage by insects or disease, as well as increased risk of fire. These factors make it difficult to provide an accurate estimate of the effects of increased levels of atmospheric CO_2 on ecosystems (Díaz-Fierros and Vallejo, 2005; Gracia et al., 2005).

This is further complicated by the fact that the increased temperature may cause an important increase in the decomposition of soil organic matter (Bottner et al., 2000). Thus, although there is evidence that the rate of soil respiration is relatively insensitive to moderate changes in environmental temperature, it is now suspected that increased temperature may be causing the loss of C from soil. In a recent study carried out in England and Wales (Bellamy et al., 2005) it was found that the soils in these regions are losing C at a rate of 0.6 % per year. Given that this loss is produced independently of land use, the effect has been attributed to increased temperature. One example of how temperature affects the mineralization of organic matter in Galician soils is shown in the models of Leirós et al. (1999).

Finally, defrosting of frozen soils also leads to high emissions of CO_2 (Turetsky et al., 2002).

Management of agroforestal systems to minimize ghg emissions

Management of terrestrial ecosystems may contribute to mitigating the concentrations of GHG by three means: a) conservation: maintenance of existing amounts of C to avoid atmospheric emission; b) sequestration: increasing the amount of C retained in the ecosystems by the CO_2 existing in the atmosphere; c) substitution: the substitution of biological products by products that consume fossil fuels to reduce emissions of CO2, for example the use of wood in buildings to reduce the amounts of cement and aluminium used, as the elaboration of these products involves high energy consumption and emission of CO_2. The present text concentrates on the first two aspects (IPCC, 2001).

1. Conservation of natural forests

Forests in which the rate of exploitation is similar to the rate of growth constitute a source of timber while at the same time conserving the amounts of C captured. This situation has been produced in many of the oak and beech forests in mountainous areas in Galicia. In some cases, the difficult access has allowed conservation of these forests in which very large amounts of C are stored in trees of large diameter (Figure 11; Merino et al., 2007).

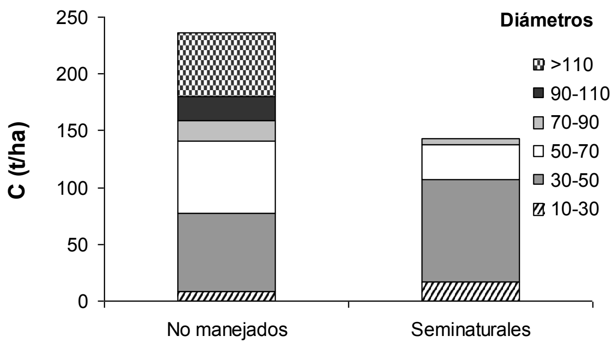

***Figure 11**: C contents in tree biomass in natural and semi-natural beech forests in Galicia (Merino et al., 2007).*

At present, the depopulation of mountainous areas means that the pressure on these forests has decreased considerably. The amounts of C accumulated in the biomass in adult stands in fragmented beech forests in Galicia are shown in Fig. 6. Comparison of the stands that have not been exploited with those subjected to selective felling over several decades shows that the recovery of these systems (and their possible expansion) involves accumulation of large amounts of C. Conservation of these systems, which is a process of fragmentation, will contribute to preserving their biodiversity, as well as conserving soils and waters.

2. Increase in forest cover

Given that agricultural land generally functions as a GHG emitter and forest land as a carbon accumulator, the increase in forest cover contributes to fixing some of the atmospheric CO_2. The increases the amount of biomass also contributes to increasing the content of soil organic matter. The transformation of agricultural land to grassland, in which tillage is less intensive, provides an opportunity to retain C, mainly in the soil (Table 2; Soussana, et al., 2004).

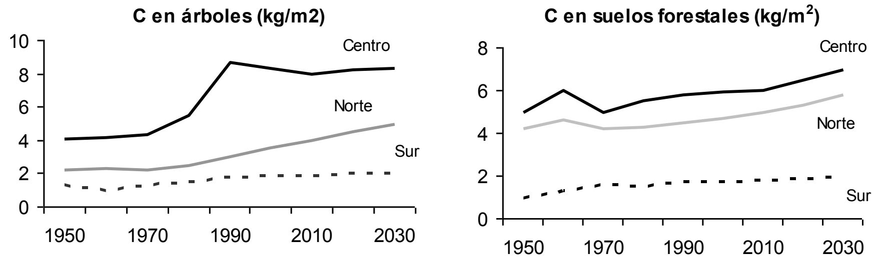

***Figure 12**: Changes in C retained in tree biomass and soils in Europe throughout the past few decades (Liski et al., 2002).*

The recovery of forest land in Europe during the past few decades has led to an increase in C reserves in both tree biomass and in soil (Figure 12; Liski et al., 2002). The amount of C accumulated in tree biomass and forest soils in Europe in the past decades has been particularly high in central and northern Europe (Fig. 12). Recent data show that forest systems in Europe store between 9 and 12 % of the anthropogenic emissions of CO_2, whereas storage of C in soils currently accounts for 3 % of these emissions (Liski et al., 2002).

Spain is one of the countries that has contributed most to the increase in forest land in Europe, partly due to the abandonment of vineyards and other agricultural land, which had become marginal. Since 1994, a total of 600,000 ha of agricultural land has been transformed to forest land within the national reforestation programme. In Galicia, in the 11 years between the second and third national forest inventories (1986 -1997) the amount of C stored in tree biomass has increased by 50 % (Xunta de Galicia, 2001). This accumulation has been due to the increase in forested land (34 %) and to a greater accumulation of C per ha (12 %).

The results observed in Catalonia (Romanyà et al., 2000; Paul et al., 2002)) indicate that reforestation of cultivated land has led to accumulation of between 0.2 and 0.8 Mg C/ha/year. The greatest accumulations of C in soils are found in areas repopulated with broadleaf species and N-fixing species (as the principal species or in the understorey). Although the accumulation of C in soils is more gradual than in plant biomass, the C is incorporated into highly stable organic compounds that are resistant to degradation (fulvic and humic acids). Thus, it has been estimated that the C content in some organic substances in these soils will remain stable for between 1000 and 3000 years (Carballas et al., 1980).

A large part of current research is focussed on understanding mechanisms of C sequestration in soil. Some studies involve estimation of the potential accumulation in terms of parameters such as soil texture and structure, precipitation and temperature. Others attempt to identify which soil fractions have the greatest potential to store C. These studies have revealed that the soil organic matter is protected in the finest aggregates (as an example of one such study, see Degryze et al., 2004).

3. Silvicultural management

The accumulation of biomass and carbon in forest stands may be increased in different ways (Gracia et al. 2005), for example: protection against fire; control of diseases and pests; changes in rotations; control of density; improvement of nutritional status; selection of appropriate species and genotypes; the use of biotechnology and management of felling remains, amongst many others. Most of these activities can increase the rate of accumulation of C by between 0.3 and 0.7 tC/ha/year.

Most forest plantations in Galicia are deficient in at least some nutrients and improvement in nutritional conditions will therefore contribute to improving production and the rates of accumulation of C (Merino et al., 2003). Improvement of the health status of stands will also have the same effects. In other regions with hydric deficits, improved hyric regimes will have important effects (Madeira et al. 2002). The accumulation of C in tree biomass is very high in plantations destined for energy production, in which the plantation density is very high and thinning is not carried out (Macías et al., 2001; Balboa et al., 2005).

The treatment of felling remains may partly mitigate the losses produced during felling (Turner and Lambert, 2000). Felling remains accumulate 20-35 % of the C content of a tree, and therefore their presence contributes to maintaining the levels of soil organic matter. Some authors (e.g. Lal, 1997) estimate that 15 % of C in these remains may be transferred to the soil organic matter.

The effects of fires on soil C are highly dependent on the fire intensity. Restricted burning of felling remains usually only affects the organic humus layers, and does not alter the C content in the mineral soil. Increases in soil C have also been attributed to invasion by N-fixing plants following controlled burning. In contrast, forest fires usually lead to substantial losses of C. Intense fires have been reported to lead to losses in the upper 5 cm of soil of up to almost 20 % of C (Fernández et al., 1997).

4. Energy plantations

Until the 1960s the use of forests as a source of energy was very important, and this capacity is now being recovered with the aim of reducing our dependence on fossil fuels. The installation of energy plantations involves a more rational use of this type of exploitation as it avoids degradation of natural ecosystems. Amongst potential forest species, the Salicaceae (genera Populus and Salix) are theoretically of most interest, as they multiply readily, are highly productive and have a low sprouting ability. These characteristics make these species readily adaptable to short rotation silviculture for forest biomass production. The species are planted at high densities (of between 10,000 and 20,000 stems per ha) with relatively low rotations (3-6 years), which results in a high degree of C capture in biomass. As these plantations are usually established in marginal land, this also provides a chance to restore the amounts of C in the soils

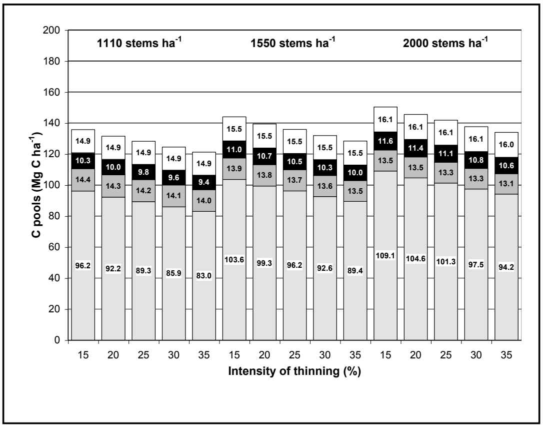

***Figure 13**: The higher the planting density and the lower the degree of thinning, the greater the potential for C capture.*

5. Management of agricultural land

Most of the C in agricultural systems is stored in soils, in the form of organic matter. Part of the C in these soils that is lost through intensive management can be recovered through agricultural and soil management (Table 2).

Table 2. Potential for C sequestration in agricultural and forest systems in temperate and cold regions (IPCC 2001)

Activity	Rate of C sequestration (kg C/ha/year)
I. Transformation of use	
1. Restoration of degraded environments	200-800
2. Restoration of mines	200-500
3. Restoration of wetlands	500-1000
II. Agriculture and silviculture	
1. Agriculture: conservation tillage, rotations, organic fertilizers,...	200-600
2. Grasslands: grazing control, improved species, fire management	200-400
3. Forest systems: selective cutting, non intensive preparation, nutrient management	100-200
III. Urban land	
1. Gardens	200-500
2. Recreational land	400-600

Different systems of soil conservation, in which the intensity of tillage is reduced and large amounts of felling remains are left on site result in decreased rates of organic matter mineralization and at the same time, increased crop production. An example of this can be seen in the study by Díaz-Raviña et al. (2005).

The application of organic amendments and waste products, such as manure (Sánchez and Dios, 1995), compost (Domínguez and Barral Silva, 2004), sludges (López Mosquera Mosquera et al. 2000; Mosquera Losada et al., 2001) and ash (Solla Gullón, 2004), prevents loss of organic matter from the soil. The use of improved varieties of crops and irrigation are also important in this sense. However, some of these practices may indirectly cause increases in emissions of CH4 and N_2O. It is therefore important to improve the efficiency of these inputs and avoid application of waste substances in wet areas.

The use of protective or green manure crops increases the content of soil organic matter due to the large amounts of roots. In grasslands, planting N-fixing leguminous plants, and reducing the intensity and frequency of grazing stimulate productivity and favour C storage in soils. Perennial species (grassland or forest) or silvopastural systems can be established in marginal land (Rigueiro Rodríguez et al., 1998). Use of these strategies may lead to restoration of between a half and two thirds of the C lost from soils within 50 years (IPCC, 2001, Freibauer et al., 2004).

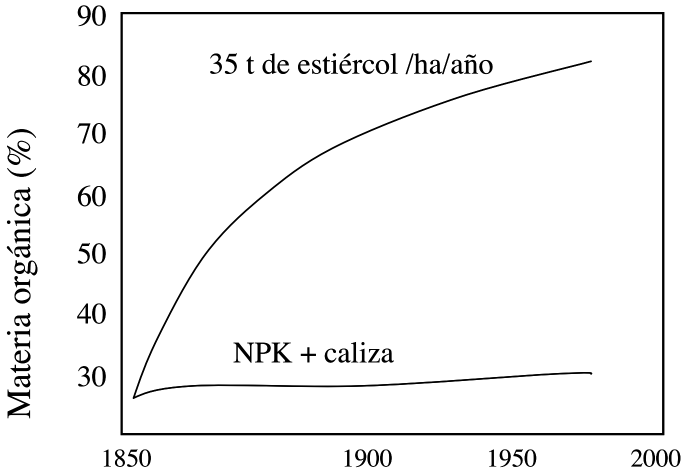

***Figure 14**: The continual input of organic waste to soil results in restoration of soil organic matter.*

6. Protection and restoration of peat land and wetlands

Approximately 30 % of the C accumulated in the soils worldwide is accumulated in wetland soils, particularly peat soils (Histosols). In the whole of Spain, the mean content of organic C in Histosols is 888 t C/ha, (mean value of 76 t C / ha in Spanish soils, Rodríguez Murillo, 2001). Although they only account for 0.2 % of the soils in Spain, these soils accumulate 2 % of the C stored in soils (Rodríguez-Murillo, 2001). The calculations of Pontevedra Pombal et al. (2001) in two peat soils in Galicia reveal accumulation rates of between 330 and 420 kg/ha/year in the last 4000 years. It is also important to note that the studies carried out by Martínez Cortizas et al. (2001) dates these soils at up to 17000 years BP, which reflects the long life of the C retained in these soils.

The great potential for retaining C in degraded wetlands and peat soils can be recovered by restoring the hydrological conditions. The Xunta de Galicia has recently published an Inventory of wetlands in Galicia (Xunta de Galicia, 2000).

7. Retention of C in mine soils and other highly degraded areas

The recovery of abandoned mine soils and other degraded areas provides another opportunity to retain C, while also improving the environmental conditions of these areas. Mine soils contain low amounts of organic matter, and their transformation to grasslands or their reforestation involve gains in C, estimated at between 0.2 and 1.85 t C/ha/year (Ussiri and Lal, 2005). The data obtained in different mines in Galicia demonstrate large accumulations in both soil and vegetation (Leirós et al., 1993; Macías et al., 2001).

All of these data show that the accumulation of C in terrestrial systems may act as a temporary mechanism for buffering the concentrations of GHG in the atmosphere. It is important that this strategy should only be considered as a partial solution, because the accumulation of C in terrestrial systems is finite. Furthermore, these gains may be reversed, for example if the management strategies are not continued or by the effects of climate change itself. The combination of strategies adopted in a particular region depends on the socioeconomic situation in that region.

8. The Kyoto protocol and Carbon sinks

Given the possible risk of climate change brought about by human activities, different strategies are being devised to treat and maintain, and if possible diminish the concentrations of greenhouse gases. The most effective measure is to restrict the emissions of these gases to the atmosphere, but is complicated by the large technological and socioeconomic changes that are required within a short time.

A complementary method is the sequestration of C in terrestrial compartments other than the atmosphere, referred to as C sinks.

After a wide-ranging debate, the Kyoto protocol recognised the C capture derived from reforestation activities (article 3.3) and gains in C produced as a result of agricultural management (article 3.4) as accountable. However, only a small amount of C is recognised to be sequestered by this route. This, in Spain, the maximum amount allowed by this route is only 0.67 million tonnes of C. This amount could be tripled in Galicia alone.

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EXERCISES AND PRACTICALS

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Compaction

1. Two different timber-harvest methods are being tested on adjacent forest plots with clay loam surface soils. Initially, the bulk density of the surface soil in both plots was 1.1 Mg/m^3 (g/cm^3). One year after the harvest operations, plot A soil has a bulk density of 1.48 Mg/m^3 (g/cm^3), while that in plot B was 1.29 Mg/m^3 (g/cm^3). Interpret these values with regards to the relative merits of systems A and B, and the likely effects on the soil's function in the forest ecosystem.

2. For the forest plot B, what was the change in percent pore space on the surface soil caused by timber harvest? Would you expect that most of this change was in the micropores or in the macropores? Explain

$$\% \text{ pore space} = 100 (Db/Dp*100)$$

Erosion rate assessment through the Universal Soil Loss Equation (USLE) in forest plantations

USLE has been designed to predict the surface erosion as a consequence of the alterations in soil properties. It is useful, therefore, to predict the effects of the different forest techniques and managements.

$$A = R \cdot K \cdot L \cdot S \cdot C \cdot P$$

In this practice we employ the USLE in three adjacent plots:

a) A mature forest plantation of *Eucalyptus spp.* The plot shows a tree cover of more than 75 % and more of the 80 % of the land was covered by litter and vegetal debris.

b) In an adjacent area, there is the same plantation. However, in the previous clear cuttings (3 rotations), the logging residues have been removed (whole tree harvesting) for fuel purposes.

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The repeated removal of logging residues has led to changes in some soil properties (organic matter, permeability and structure). Another effect is the lower cover by litter and vegetal debris in the soil, which means a higher C factor value. In this case, the percentage of land covered by debris is 40 %.

c) This plots is the same that the original mature plantations (a) after a severe wild fire. In this case, there were changes in the soil structure, permeability and organic matter.

DATA OF THE STANDS

		Plantation	Logging residues removal	Wild fire
Climate				
	Factor R	300	300	300
Soil				
	Sand	7 %	7 %	7 %
	Very fine sand	11 %	11 %	11 %
	Silt	51 %	51 %	51 %
	Clay			
	Organic matter	8 %	6 %	5 %
	Structure	Very fine granular (1)	Granular fine (2)	Granular fina (2)
	Permeabilidad	Rapid-Moderate (2)	Moderate (3)	Modrate-low (4)
Topografy				
	Lenght of the slope	300 m	300 m	300 m
	Steepness of the slope	30 %	30 %	30 %
Cover and management				
	Factor C	0.013	0.09	1
	Factor P	0.1	0.1	1

Questions

1. **Soil Erodibility Factor de K**

a. Identify the changes in the soil properties as a result of the logging residues removal and the wildfire.

b. Calculate the factor K in the three soils using the data given in the previous table

$$K = 2.1 \cdot M^{1.14} \cdot (10^{-6})(12\text{-}a) + 0.0325\ (b\text{-}2) + 0.025\ (c\text{-}3)$$

where M = (% silt + very fine sand) (100- % clay), a is the percentage of organic matter, b is the structure of the soil (1, 2, 3 o 4) and c is the permeability class (1 a 6). The values obtained are in Tons/acre units; to transform this value in tons/ha, this value should be multiplied by 1.292.

c. Discuss the variations in the factor K. Identify the reasons of these changes?

2. **Calculate the Factor LS from the data of the table**

$$LS = (x/22.13)^{0.5} \cdot (0.065 + 0.045s + 0.0065\ s^2)$$

where x is the lenght of the slope, and s is the steepness of the slope.

3. **Taking into account the values of the factors R, K, LS, C and P, calculate the rate of erosion in each of the three stands.**

Interprete the different results.

Write the results in the following table

Resultados

	R	K	LS	C	P	A
P1	300	0.08	26.75	0.01	0.10	0.79
P2	300	0.29	26.75	0.09	0.10	20.88
P3	300	0.29	26.75	1.00	1.00	2361.14

4. **Assessment of the nutricional status in forest plantations subjected to different managements**

In this practice we are going to carry out the assessment of nutritional status of a plantation of a young *Pinus radiata* plantation subjected to different treatments. In the stand there are three adjacent areas with different management: a) logging residues removal, b) logging residues removal + addition of wood ash and c) logging residues removal + addition of sewage sludge.

In the table below you will find the data of soils, plantations (selviculture and foliar nutrients concentrations) and c) chemical composition of the wood ash and sewage sludge employed.

Questions

1. Assess the main general limitations of the stand (plot without any treatment)

   a) Steepness of the slope

   b) Soil depth

   c) Soil fertility

   d) Levels of nutrients in the plant

2. Discuss the different chemical composition of the two wastes employed

3. Discuss the changes in the soil properties attributable to the treatments

   a) Soil nutrients

   d) Foliar concentrations of nutrients

Table 1. Chemical composition of the a) wood ash and b) sewage sludge.

	Wood ash	Sewage Sludge
pH	10.4	10.0
Total C (g kg^{-1})		292.0
Total N (g kg^{-1})	5.56	64.0
P (" ")	2.6	13.0
K (" ")	111.1	14.0
Ca (" ")	25	23.4
Mg (" ")	6.0	3.0

CHARACTERISTICS OF THE PLANTATION

TYPE OF PLANTATION

Species: *Pinus radiata* **Age:** 5 años

Ground vegetation: *Daboecia cantabrica, Ulex europaeus, Erica cinerea, Calluna vulgaris, Rubus sp.*

TOPOGRAFY

Altitude: 350 m **Steepness:** 30 %

GENERAL CONDITIONS OF THE SOIL

Parent material: Granite

Surface rocks: No se aprecia.

Soil Depth: 60 cm (Ah = 0–25 cm; AB = 25-60 cm).

Drainage: Moderare/rapid.

SYLVICULTURE

Land preparation: Mechanical brushing, subsoiling, fertilization (Osmocote).

900 trees/ha.

GROWTH DATA
DBH: 10.9 cm

H: 7.02 m

Analysis of soils and plant

Soil

Horizont	Plantation	Logging residues removed	LRR + wood ash	LRR + sewage sludge
pH	3.9	3.9	4.2	4.3
O. M (%)	8	6	7	8
P (mg/kg)	5.4	4	15	12
K (mg/kg)	73.2	67	120	70
Ca (mg/kg)	144	120	400	600
Mg (mg/kg)	27	16	60	80

	Very low	Low	Optimum	High
Mg (mg/kg)	0-20	20-60	60-120	120-160
Ca (mg/kg)	0-400	400-800	800-1200	1200-2000
K (mg/kg)	0-80	80-170	170-280	280-430
P (mg/kg)	0-10	10-30	30-50	50-75

Nutrient concentration in tree needles (mg g^{-1})

S	N	P	K	Ca	Mg	Mn
1,72	16,10	0,61	2,52	0,45	0,74	0,200

	N	**P**	**K**	**Ca**	**Mg**
Defficient	< 12	< 1,2	< 3	< 0,6	0,7
Marginal	12-15	1,2-1,4	3-5	1	0,7-1
Satisfactory	15	> 1,4	>5	> 1	>1

Carbon gain in tree biomass and soil after reforestation

1. Calculate the C accumulated in the tree biomass using the general data of the stand and the allometric equations

Stand of Pinus radiata, 30 years old

Diameter (DBH): 40 cm

High: 26 m

Density: 850 trees/ha

Componentes	Ecuaciones de biomasa	r^2	Concentración de C (mg g^{-1})	
Madera	$W = 0.0123 \cdot d^{1.6042} \cdot h^{1.4131}$	0,960	0.504	Aereal tree biomass
Corteza	$W = 0.0036 \cdot d^{2.6564}$	0,920	0.541	
Ramas gruesas	$W = 1.937699 + 0.001065 \cdot d^2 \cdot h$	0,660	0.513	
Ramas finas	$W = 0.0363 \cdot d^{2.6091} \cdot h^{-0.9417}$	0,810	0.525	
Ramillos	$W = 0.0078 \cdot d^{1.9606}$	0,690	0.532	
Acículas	$W = 0.0423 \cdot d^{1.7141}$	0,790	0.527	

2. Calculate the C gain in the litter layer

Three simples werer taken using a frame of 30x30cm.

Concentration of C= 48,3 %

Dry weight of the samples, in kg: 1.02, 2.34, 0.82

3. Calculate the C gain in the mineral soil

Cropland soil

	Bulk density (g/cm^3)	Stoniness (%)	C concentration (%)
0-5	0.97	15.8	3.4
5-15	1.0	16.2	2.8
15-30	1.0	17.0	2.2

Forest soil

	Bulk density (g/cm^3)	Stoniness (%)	C concentration (%)
	BD	S	C
0-5	0.8	16	3.4
5-15	0.9	17	2.8
15-30	0.93	18	2.2

Soil Protection in Sloping Mediterranean Agri-Environments
Lectures and exercises

aims at providing basic tools to assess soil degradation and to design soil protection initiatives in Mediterranean sloping areas. Rooted in both the EU thematic strategy for soil protection in Europe and the special environmental sensitivity of Mediterranean slopes, it is oriented towards the capacitation of post-graduation students from agricultural, forest or environmental engineering and from life or earth sciences.

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