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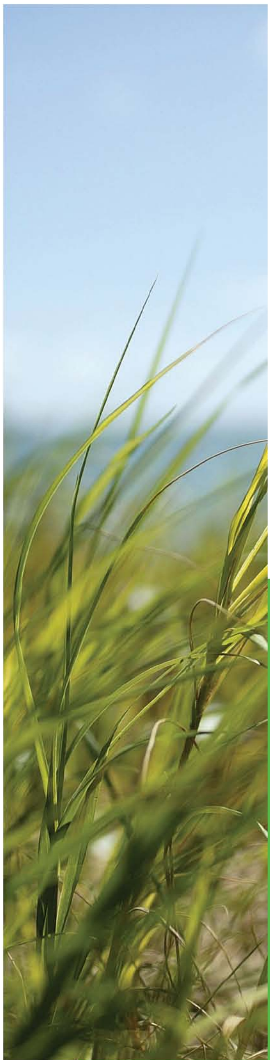

Agriculture and Rural Development

Culture and Education

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THE CHALLENGE OF DETERIORATION OF AGRICULTURAL LAND IN THE EU AND IN PARTICULAR IN SOUTHERN EUROPE

STUDY

EN

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EUROPEAN PARLIAMENT

DIRECTORATE GENERAL FOR INTERNAL POLICIES

POLICY DEPARTMENT B: STRUCTURAL AND COHESION POLICIES

AGRICULTURE AND RURAL DEVELOPMENT

The Challenge of Deterioration of Agricultural Land in the EU and in Particular in Southern Europe

STUDY

This document was requested by the European Parliament's Committee on Agriculture and Rural Development.

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AGRICULTURE AND RURAL DEVELOPMENT

The Challenge of Deterioration of Agricultural Land in the EU and in Particular in Southern Europe

THE RESPONSE THROUGH EU AGRICULTURAL POLICY INSTRUMENTS

STUDY

Abstract:

Soil degradation is a natural process accelerated by human activities and involves both the physical loss (erosion) and the reduction in quality of topsoil associated with nutrient decline and contamination. It has been caused by a number of factors many of which are tied to human development as deforestation, overexploitation, overgrazing, and industrialization. They have both localised and widespread impacts and affect soil quality for agriculture.

This study aims to present the current situation of the European agricultural land and examine the possible options to stop or recover soil degradation.

IP/B/AGRI/IC/2009_26 September, 2009

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GENERAL INTRODUCTION

A. Background Information

According to the United Nations Convention to Combat Desertification (UNCCD)[1] as "land" is defined to mean "the terrestrial bio-productive system that comprises soil, vegetation, other biota, and the ecological and hydrological processes that operate within the system".

Soil is a natural body consisted by solid ingredients (minerals and organic), liquid, and gases that occurs on the land surface. It is the upper limit and the boundary between earth and air, characterized by one or more horizons, or layers, that are distinguishable from the initial material, capable of supporting life in a natural environment.

Soil can be considered a non-renewable resource, as it takes hundreds of years to produce a few centimetres of soil. To an extent, soil is a public good that provides natural resources. It is not just a commodity but on the contrary it should be a partner in agricultural production. Although soil is the basis of all economic and cultural activities however its economic value is barely recognised.

Soil degradation is a natural process, accelerated by human activities and involves both the physical loss (erosion) and the reduction in quality of topsoil associated with nutrient decline and contamination. It affects soil quality for agriculture and has implications for the urban environment, pollution and flooding. The soil degradation increases where activities, either directly or indirectly, provoke the reduction of its vigour and health. The ultimate degradation is the removal or loss of its physical components.

Since the middle of the nineteenth century soil degradation has been increased in response to the growth in world population and human technical capacity. Cultivation of land for agricultural production, deforestation, grazing of natural range, and other disturbances of the natural cover of the soil has been intensified. So accelerated soil deterioration of the farm land has been the absolute and uncontradictable consequence all over Europe.

During the 20th century, climatic factors were responsible for desertification mainly in the Mediterranean region, due to the long periods of droughts. Present land degradation in Northern Mediterranean countries is partially intensified by the dramatic land use changes and in many cases lead to an unstable state of ecosystems. In most cases natural and agricultural ecosystems that were affected are hard to recover.

Soil degradation has strong impacts on other areas of common interest to the EU, such as water, human health, climate change, nature and biodiversity protection, and food safety. Soil protection is not only a national concern as soil contamination in one Member State can have cross border effects and cause pollution and economic burdens on neighbouring countries.

A soil can degrade in 3 ways:

- Physical, chemical or biological run-down causing a reduction in vigour. This can result from excessive product removal (depleting soil nutrients), reduction in plant growth, lowered organic cycling, increasing soil temperatures, leaching, compaction and surface crusting.
- Reduction in mass and volume through erosion. This reduces the physical size of the soil ecosystem.

[1] The United Nations Convention to Combat Desertification (1994), (UNCCD).

- Accumulation of specific soil chemicals to levels that detrimentally effect plant growth. Such materials include: soluble salts (causing salinity); hydrogen ions (causing acidification); and, some chemicals from industrial, mining and agricultural activities (chemical contamination).

The first global survey of soil degradation was carried out by the United Nations in 1988-90. This survey is known as GLASOD [2](Global Survey of Human-Induced Soil Degradation). More recently in 2004 the study "Land Degradation and Land Use/Cover Data Sources"[3], presents the actual status of soil degradation by mapping the degree to which the soil was degraded and the percentage of the global area affected. At the same time determines the responsible physical or human intervention that causes the corresponding soil degradation.

On the global basis, the soil degradation is caused primarily by overgrazing (35%), agricultural activities (28%), deforestation (30%), and overexploitation of land to produce fuel wood (7%), and industrialization (4%).

The patterns are different in the various areas. In North America, agriculture has been responsible for 66% of the soil loss, while in Africa, overgrazing is responsible for about half of the soil degradation.

In many regions across the EU soil is rapidly degrading by human activity, such as certain agricultural and forestry practices, industrial activities, tourism or urban development. An estimation of 115 million hectares or 12% of Europe's total land area are subject to water erosion, and a further 42 million hectares by wind erosion. Approximately 3.5 million sites within the EU could be contaminated. About 45% of European soils have low organic matter content, principally in southern Europe but also other Member States are concerned.

These figures illustrate how pervasive is the problem of soil degradation. No continent is free from the problem. Areas of serious concern include zones where up to 75% of the topsoil has been already lost.

The **loss of arable land** has been caused by a number of factors, many of which are tied to human development. The primary causes are deforestation, overexploitation, overgrazing, agricultural activities and industrialization and they have both localised and widespread impacts.

Acidification, salinity, organic depletion, compaction, nutrient depletion, chemical contamination, landslides, and erosion are all forms of farmland degradation that can be brought about by inappropriate land use practices. In fact if production is not carefully matched to land capability, then it is difficult to achieve sustainable land use.

Climate change accelerates farmland degradation. Extreme weather conditions have become more common, with an alternation between periods of drought and extreme rainfall events, which speed up lithosphere degradation processes, in particular in the areas of South of Europe, where soils are more vulnerable.

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[2] Global Assessment of Soil Degradation (global study published in 1990 by UNEP and ISRIC in cooperation with Winand Staring Centre, ISSS, FAO and ITC)

[3] The project is a part of the Millennium Ecosystem Assessment. The results of the study and the descriptions of country level data used were presented in Lepers (2003) and on the Internet at http://www.geo.ucl.ac.be/LUCC/lucc.html.

A specific expression of land degradation processes is **desertification**. It is a concept applied by scientists and policy makers defined by United Nations Convention to Combat Desertification (UNCCD)[4] as "the degradation of the land in arid, semi-arid and dry-sub-humid areas, as a result of several factors, including climatic change and human activities".

B. Regulatory framework and Initiatives

In the past EU failed to protect land sustainability at a European level, even though soil is a resource of common interest. Although policies already adopted in the EU contribute to soil protection, no coherent policy exists. Only few Member States have specific legislation on soil protection, often covering a specific threat, in particular soil contamination.

Within the context of soil conservation strategy, the 'good agricultural and environmental condition' principles established under the CAP should lay greater emphasis on measures to improve the operability of existing irrigating systems, combining traditional agricultural systems with action to restore the existing water sources.

Recently the European Commission published a communication "Towards a Thematic Strategy for Soil Protection"[5] and a proposal for a "Soil Framework Directive"[6], as foreseen in the 6th Environment Action Programme[7]. The communication outlines the scope of such a strategy and deals with soil protection. The major threats for soil identified in the communication are erosion, decline in organic matter, contamination, sealing, compaction, biodiversity decline, salinisation, floods and landslides. The Framework Directive sets out common principles, objectives and actions. It requires Member States to adopt a systematic approach to identify and combat soil degradation, tackling precautionary measures and integrating soils protection into other policies.

The European Parliament adopted the proposal for the directive at first reading in November 2007[8], strongly emphasising the need for protecting soils against the negative effects of climate change.

The Ecologic & French Geological Survey Institute (BRGM) in collaboration with the European Commission has published an assessment[9] regarding the cost of soil degradation in Europe, as a contribution to the development of a European Soil Strategy. This assessment presents an estimation of the economic consequences that the continued degradation of European soils implies.

In addition different EU policies (for instance on water, waste, chemicals, industrial pollution prevention, nature protection, pesticides, agriculture-in the framework of the health check) are contributing to soil protection. In the same direction the European Parliament adopted a resolution on the water scarcity and droughts in the European Union[10] and a resolution related to the challenge of deterioration of agricultural land in the EU and in particular in Southern Europe.[11]
However all these policies are not sufficient to ensure an adequate level of protection for farm land in Europe and more specifically **for the vulnerable soil of southern Europe** because they have other aims and other scopes of action to serve.

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4 The United Nations Convention to Combat Desertification (1994) (UNCCD)
5 Soil Thematic Strategy (COM(2006) 231)
6 Proposal for a Soil Framework Directive(COM(2006) 232)
7 The 6th EAP is a decision of the European Parliament and the Council adopted on 22nd July 2002. It sets out the framework for environmental policy-making in the European Union for the period 2002-2012 and outlines actions that need to be taken to achieve them.
8 Resolution of 14 November 2007 on the proposal for a directive of the European Parliament and of the Council establishing a framework for protection of soil and amending directive 2004/35/EC
9 Assessing the Economic Impacts of Soil Degradation, Study ENV.B.1/ETU/2003/0024, Dec. 2004.
10 INT/2008/2074 Addressing the challenge of water scarcity and droughts in the European Union
11 INI/2008/2219 (Aita-It) Challenge of deterioration of agricultural land in the EU and in particular in Southern Europe: the response through EU-agricultural policy instruments

In the light of this situation, initiatives should be examined to combat the degradation of agricultural soil, reassuring at the same time its recovery. In addition measures towards the sustainable use of farmland and the management of the soil and water resources are necessary to be adopted.

In order to allow the members of the Committee on Agriculture and Rural Development of the European Parliament to make fully informed decisions, three notes were asked to be submitted including:

a) Presentation of the situation for the European agricultural land and examination of the possible options to stop or recover soil degradation.

- To describe the current situation of the soil degradation in the EU and its impact to the European agricultural production, with special reference to the situation in the South of Europe.
- To analyze, in short, the types of soil degradation apparent in southern Europe including soil erosion, salinization, nutrient depletion, and desertification.
- To assess the effects of soil degradation on production capacity, with special reference to the farm land in southern Europe, where soil degradation process is already apparent.
- To describe measures to be undertaken in order to combat desertification and mitigate its effects in the countries of southern Europe experiencing serious droughts, with view to achieve an improvement in the affected areas.
- To examine the effectiveness of a better co-ordination of the existing EU policies.
- To examine some options protecting soil as reducing mechanical operations using appropriate techniques, working across slopes where safe to do so, using low ground pressure set-ups on machinery, shepherding livestock and moving forage areas, planting and/or maintaining hedges or shelter belts to reduce wind erosion, determining of what is an inappropriate land use practice, depending on the robustness of the land and its climate, avoid practices of large scale mechanized monoculture that intensify soil decline.
- To propose measures that protect soil organic matter including returning straw or other crop residues after harvest, crop rotation, applying animal manure and compost, using reduced or shallow cultivation to maintain or increase near-surface organic matter.
- To evaluate the existing irrigation methods in order to ensure optimising the management of available water resources. As water collection and distribution systems for irrigation will become increasingly costly, new and/or modified irrigation methods will accordingly need to be examined in order to reduce irrigation volumes and water extraction from aquifers as well.

b) Examination of a case study of soil degradation in southern Europe.

A project is presented including an exemplary case study that will illustrate the extent of soil degradation (e.g. salinization) in a region of Portugal.

c) Conclusions

The notes arrived to some conclusions assessing the scale of the potential losses for the EU farmers of southern Europe, in the case that no measures are going to be implemented in the following years.

The notes provided ideas and practical proposals for consideration in due course with view to formulate a common strategy for the recovery, conservation and improvement of agricultural soils, minimizing artificially accelerated soil deterioration. It is clear that one of the priorities must be to draw up a common action plan, including a schedule for action to prevent degradation and protect farmland. The morphological features of soils in southern Europe constitute an example of what could occur in various rural areas in northern Europe in the future.

In addition analysis leaded to some conclusions referring to:

- The possible management of soil on the basis of existing EU policies, in order to meet future challenges, avoiding negative effects on human health, natural ecosystems, climate change, and on the economy as well.
- The possible measures to be undertaken, emphasising to the appropriate interventions for the maintenance and recovery of the agricultural ecosystem and water management.

2. Interventions for the Maintenance and Recovery of the Agricultural Ecosystem: Water Management

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Abbreviations and Acronyms

IPCC Intergovernmental Panel on Climate Change

UAA Usable agricultural area

Executive Summary

1. Soil and water play a vital role in maintaining ecosystems and aiding regions' social and economic development. The use and management of these resources should be guided by sustainability criteria.

2. The environment of Mediterranean Europe is characterised by irregular and intense precipitation, high levels of evapotranspiration, problematic topography and mankind's intensive and long-running use of land. These factors have determined the annual and interannual availability of water resources and the level of erosion.

3. Recent changes in the use of land (more intensive farming and agricultural abandonment) have become a new and prominent factor in the development of water and soil resources in Mediterranean Europe.

4. Encouraged by the profitability of irrigation, public authorities have promoted the development of hydraulic infrastructure with a view to ensuring that large tracts of farmland have access to water. Irrigation in its current form largely fails to combine efficiency with sustainability. The systems in use lose large quantities of water and contribute to erosion. Irrigation in arid or semi-arid areas with certain lithological conditions leads to the salinisation of water and soil.

5. Agricultural abandonment in Mediterranean mountain regions has wrought drastic changes on the landscape. It initially accelerated the erosion process on the slopes. Over time, plant recolonisation took place (shrubs appeared first, followed by forests), providing soil cover. All research indicates that, as things stand, headwaters of rivers and ravines have less water as a result of greater consumption by vegetation. On the other hand, less sediment is transported, thanks to the restraining effect of this vegetation.

6. Dry farming results in runoff and produces sediment, as, for much of the year, the soil does not benefit from the protection of plant cover. There is marked erosion during storms of high hourly intensity, in particular among crops grown on hillsides (vines or cereals). Simple soil conservation measures could prevent the problems associated with storms of average and moderate intensity.

7. Policies should be drafted and measures applied that are designed to rationalise water consumption and reduce soil losses through erosion. The following are worthy of particular mention:

   - The gathering of data and scientific findings that will enable us to take more appropriate decisions and the forging of close relations between scientists and other stakeholders to ensure the satisfactory transfer of information.
   - Adequate territorial planning and management using drainage basins as reference areas at various levels.
   - Caution should be exercised as regards any measures on or changes to the use of land at the headwaters of rivers, as there could be major repercussions in terms of runoff or increased flow.
   - The interbasin transfer of water should be seen in the context of overall water management in terms of sustainability and rational use.

- Substantial improvements are required with regard to current irrigation water distribution systems, along with the use of new techniques to reduce consumption. It is essential for public authorities to be involved in this technological improvement and for there to be public and private investment in agricultural research, development and innovation.
- In some regions, measures to improve existing irrigation may prove more worthwhile than expansion to new areas.
- Soil erosion is a serious environmental problem. Action is needed in the form of awareness campaigns, studies aimed at identifying better tillage systems and the promotion of soil conservation through investment and aid.
- Up-to-date knowledge regarding the causes and consequences of the improper use of water and soil degradation and methods of prevention should be made available to the public. Awareness may be part of the solution to the problem.

Introduction

Sustainability is a priority in water and soil management. These resources deserve special attention, because, in addition to being essential for the functioning of ecosystems, they have a role to play in regions' social and economic development Furthermore, water is becoming a key element in territorial planning.

Water is crucial to farming and is a decisive factor in pollution and erosion. The latter has far-reaching implications, as the loss of fertile soil is accompanied by a decline in the potential productivity and biodiversity of the region in question.

This paper examines the impact of the recent changes to land use on water and soil resources in Mediterranean Europe. It also sets out a series of conclusions and measures to ensure better use of these resources in future. However, it is appropriate to begin by defining, albeit briefly, the environmental and human conditions specific to the Mediterranean region, as they explain, to a large extent, the organisation of the land, the development of its landscapes and the traditional management of water and soil resources.

1. Environmental Factors in Southern Europe

Mediterranean Europe is characterised by the fragility of its bioclimate, its mountains and the high degree of human intervention throughout history.

The fragility of the bioclimate is a result of the particular nature of precipitation in this region. On the one hand, there is great (interannual and annual) variability and, on the other, a high concentration of precipitation within very short periods of time (high hourly intensity), especially in autumn. It is no surprise that a large number of observatories have recorded precipitation levels of more than 400 mm in 24 hours or between 100 and 200 mm in one hour (López Bermúdez and Romero Díaz, 1993; Giordano, 1986).

This precipitation activity has a decisive impact in terms of the following: a) the variability of water reserve levels; b) the system of water courses; and c) contribution to erosion processes. Intense rainfall causes the formation of gullies, earth movements and flooding (Gallart and Clotet, 1988; García Ruiz et al., 1996).

On the other hand, the period in which precipitation is at its lowest, summer, coincides with the highest temperatures. This means that it is during this season that plants suffer from long periods of water shortage, in an environment in which the volume of plant biomass per unit of area is low and there are scant possibilities for plant recovery.

The mountainous nature of the region and its soils also play an important role in the hydrological and geomorphic cycles of Mediterranean Europe. The marked difference in altitude between the mountain summits and the nearby coastline accelerates the flow of water not absorbed by the soil, triggering the erosion process. At the same time, many Mediterranean soils either develop lithological conditions that offer low resistance to the erosive effect of water (marl or clay) or are very susceptible to physical degradation (sealing, subsidence or the formation of surface crusts), as they do not benefit from plant cover (Poesen and Hooke, 1997).

Mediterranean Europe has been occupied by man since ancient times and farmed intensively since the Neolithic Age. The human presence was the cause of major changes to the natural landscape. The need for agricultural land and pasture made large-scale deforestation necessary, stripping the soil of its protection. The constant pressure from humans has resulted in some areas in a very advanced state of soil degradation, and a consequent reduction in production capacity.

For at least a century, population growth, changes to land use as a result of market conditions and more intensive crop farming have led in some areas to greater erosion and overexploitation of water resources with the result that both processes now constitute a serious environmental problem. On the other hand, other parts of the Mediterranean region, which have been affected by the rural exodus and the decline in farming, have been restored to a more natural state as a result of plant recolonisation. This new development has also had an impact on the hydromorphic conditions of hillsides.

Recent changes to land use have therefore had a decisive impact on the state of water and soil resources in Mediterranean Europe. A particular role has been played by the expansion of irrigated areas, agricultural abandonment in mountain areas and dry farming.

2. The Expansion of Irrigation and Water Resources

The profitability of irrigation farming and its image as the driver of growth within the agricultural sector, playing a major role in creating jobs and economic prosperity, has caused the area given over to irrigation in Mediterranean Europe to continue to grow.

In Spain, there are more than 3.7 million hectares of irrigated land, treble the area recorded at the beginning of the 20th century. In the Segura basin in south-east Spain, the irrigated area trebled between 1920 and 1994, aided at first by the regulation of the headwaters of the river and later by the Tagus-Segura transfer and the extraction of underground resources (Barberá et al., 1997). Frutos (1993) noted an increase of almost 80% in the irrigated area of the central sector of the Ebro Depression between 1950 and 1990, which was linked to the building of large-capacity dams.

In southern Europe, irrigation is employed on a large percentage of cultivated land and has a marked impact on final agricultural output (Table 1). In Greece, the traditional use of irrigation for horticultural products has given way to use for crops such as cotton, corn and sugar beet, with the result that irrigated land now accounts for 40% of the UAA. In Italy, this figure is 31.3%. In Spain, the nature of irrigation farming varies. Traditional irrigation prevails in valley floors and close to water courses, but, alongside it, there is now modern irrigation relying on costly infrastructure funded by public money. This kind of farming accounts for 15.1% of the usable agricultural area.

Table 1: Percentage of irrigated usable agricultural area in Mediterranean countries (2005)

	Usable agricultural area (UAA) (thousand hectares)	Irrigated area (%)
Greece	3 984	40
Spain	24 855	15.1
France	27 591	9.8
Italy	12 708	31.3
Cyprus	152	30.3
Malta	10	29.5

Eurostat Yearbook (2008)

Irrigation farming now represents the largest use of the EU's water resources, in particular in southern Europe. In these countries, irrigation accounts for more than 60% of overall water consumption. In Spain, this figure is as high as 80% (Rico Amorós, 2006). In fact, water demand for irrigation doubled there in the second half of the last century and some signs of overexploitation of underground water resources have been detected. In the near future, the balance between water supply and demand is set to move further out of kilter as a result of climate change. According to the IPCC (2007), in southern Europe climate change will exacerbate the present conditions of high temperatures and drought in a region already susceptible to climate variability.

A point that should be stressed with regard to irrigation in southern Europe concerns the technical characteristics of irrigation systems and their efficiency. In most countries, gravity systems are used, in the form of border irrigation (flooding of fields) or furrow irrigation (using channels that transport water to the fields). In Spain, these methods account for 60% of irrigation and in Italy for 51% (Dwyer, 2000). There is a significant loss of

resources from these systems because of the use, in many cases, of outdated infrastructure ill suited to water saving needs. This phenomenon is noticeable in the more intensive forms of irrigation that have followed on from the traditional methods. In the case of Spain, approximately 20% of land is irrigated, essentially using channels in the ground, resulting in heavy water losses. Meanwhile, 35% is irrigated using concrete channels, some of which bring with them serious conservation and maintenance problems. A total of 1.9 million ha continues to be irrigated using traditional methods, such as border and gravity irrigation. A study carried out with regard to irrigation within the Ebro Depression confirmed a poor level of efficiency in terms of irrigation management, as more than a quarter of the water entering the system was lost as surface runoff (Lasanta et al., 2001).

Irrigation is usually carried out on plains, as this means a lower rate of erosion and transport of suspended sediment. On hillside farmland, however, it can trigger erosion processes linked to surface runoff. In any case, the highest rates of soil loss as a result of erosion have been detected in the furrows of irrigated fields (Koluvek et al, 1993; Mateos and Giráldez, 2005).

The transport of solutes (salts and nutrients) is also marked in irrigation and, in some regions, has become the main cause of soil degradation. Studies carried out on the extensive irrigation areas in the central sector of the Ebro Depression in Spain recorded losses of 15.2 Mg ha-1 year-1, solutes (chloride, sodium, sulphate and calcium) accounting for 98.6% and suspended sediment for only 1.4% (Lasanta et al., 2001). In semi-arid climates with a high level of evapotranspiration, a prevalence of gypsum and saline deposits and an excessive use of irrigation water, salinisation processes are usually detected in the topsoil, with negative consequences for crop development. Furthermore, a large quantity of the water used in irrigation finds its way to the river network as surplus water with a high salt content. High salinity levels are therefore to be expected in rivers. The Ebro carries a total of 6.7 million tonnes of salt to the Mediterranean each year (Alberto et al., 1986).

3. Agricultural Abandonment

One of the most striking changes to the rural Mediterranean landscape has been the abandonment of farmland throughout the 20th century. This abandonment has been concentrated in the less productive regions and those which, as a result, quickly suffered the effects of emigration. In southern Europe, these regions correspond, above all, to mountain areas that do not have the advantages of high mountain areas (an abundance of grazing land and forest resources, wide and flat valley floors suitable for farming and potential tourist appeal), but are encumbered with its disadvantages (hilly topography, harsh winters, short vegetative periods and transport difficulties) (Lasanta, 1996). Since 1950, major population decreases have been recorded, in some cases of more than 70%, together with a decline in the use of traditional farming methods.

Over centuries, the slopes of the Mediterranean mountains have become cultivated areas. The plots of land were adapted to the awkward topographical conditions through the design of sloping fields and terraces, and a small-trade economy emerged enabling farmers to make a living. The area of land used for farming grew or shrank depending on population pressure. In any case, the growth of agricultural land was relatively significant for regions that did not present the best conditions for this activity. One such example is the Sierra de Cameros (Western Iberian system, Spain), where the area used for farming accounts for 32.5% of the overall territory (Oserín, 2007).

A dwindling population, poor productivity and the inability to join a competitive and open market have seen the area of cultivated land shrink, a process that has taken place over the last century at differing rates, depending on the characteristics and location of the mountain regions in question.

The changes to land use in the Mediterranean mountain region have gone together with a loss of diversity in the landscape and the disappearance of a cultural landscape that had developed over centuries (MacDonald et al., 2000). This in turn has accelerated the emergence of new hydrological and geomorphic processes. In this regard, three distinct stages have been noted: a period corresponding to peak anthropic pressure, the stage immediately preceding agricultural abandonment and, finally, the current situation, 40 to 50 years after the abandonment process began.

a. During the first stage, deforestation and agricultural activity turned the Mediterranean mountain region into an exporter of water and sediment. Statistics show that, during this period of peak agricultural use of land, many deposits were carried from the slopes to the irrigation channels, and the intensity with which they arrived prevented the stabilisation of vegetation and channels. The growing of cereals on slopes contributed to soil erosion, especially where little attention was paid to conserving resources (itinerant farming). The water channels forged in the terraces may have led to linear incisions and even to the emergence of badland areas (Gallart and Llorens, 1994). On the other hand, surface and underground water resources were more plentiful, increasing the intensity and frequency of peak flooding (García Ruiz, 1996).

b. In the years following the abandonment of land, those areas with less soil and that were rockier and on a sharper incline were affected by surface runoffs, which proved to be very common, although they eased off as time went by and plants colonised the area (Ruiz Flaño, 1993). On those plots of land subject to periodic fires, severe erosion set in, forming gullies and causing debris and rock flows.

On terraced slopes, stone walls did not receive the proper care and began to crumble as a result of small landslides, incisions and gullies (Ortigosa et al., 1994). From a geomorphological point of view, terraces traditionally acted as an effective soil conservation system across hillsides or basins. Water retention by means of infiltration and slope

reduction countered the effects of surface runoffs in terms both of erosion itself and the transport of sediment. Studies carried out on experimental basins occupied by terraces confirmed a very low level of sediment production (Llorens et al., 1992). According to Gallart and Llorens (1994), in most cases the dismantling of walls and small landslides, while spectacular, did not present a particular problem.

It was at this stage, however, that plant recolonisation began. A few years after abandonment, shrubs began to grow, slowly paving the way for the arrival of forested areas. As time went on, the spread of forests across Mediterranean mountain regions was remarkable. Within the Western Iberian system, the forested area (woods, reafforestation and shrubs) increased by 43% between 1956 and 2001 (Table 2). The spread of plant cover included both natural woodland, which doubled in area, and reafforestation (Arnáez et al., 2008). In the initial stages of growth, the latter had a negligible effect on the hillside water cycle, although it did alter the geomorphic dynamic by increasing erosion rates, mainly when the wrong reafforestation method had been used (Ortigosa and García-Ruiz, 1995). As the reafforested trees matured, the hydrological and geomorphic conditions in the basins improved: interception increased, the impact of rainfall was offset and undergrowth developed.

Table 2: Growth of forested areas within the Western Iberian system (Cameros) (1956-2001)

Valleys	Woodland (ha)		Reafforestation (ha)		Shrubs (ha)		Forested area (ha)	
	1956	2001	1956	2001	1956	2001	1956	2001
Iregua	17 033	29 856	0	3 448	22 224	14 912	39 257	48 216
Leza	3 871	9 228	13	2 020	12 184	16 146	16 068	27 394
Jubera	563	2 353	76	2 258	7 380	6 800	8 019	11 411
Cidacos	1 052	2 976	48	1 771	7 352	11 178	8 352	15 925
Total	22 519	44 413	137	9 497	49 140	49 036	71 796	102 946

Arnáez et al. (2008)

c. At present, the recolonisation of hillsides by natural vegetation and through reafforestation curbs sediment production, reduces the torrential activity of ravines and restricts the area from which sediment is transported. All of this is down to the protective effects of shrubs and forests. The plant cover also means that there is less water available at basin level, as a result of the effects of interception and evapotranspiration (García-Ruiz et al., 2001; Lana-Renault, 2007). An analysis of the water balance in various Spanish basins over the last 50 years reveals that the reduction in runoff is down not to climate variability but to the changing behaviour of river headwaters (Gallart y Llorens, 2002).

4. Dry Farming

In the dry farming areas of the plains, there have also been far-reaching changes over the last few decades. The mechanisation of farming, the common agricultural policy and the market have prompted the abandonment of less productive land and the gradual replacement of traditional crops by others more in demand on the markets. Accordingly, there has been an increase in the growth of crops such as vines and, to a lesser extent, almonds and olives.

In general, dry farming generates runoff and produces sediment, as, for most of the year, the land used has no protection from plant cover (De Santisteban et al., 2006). The impact of rainfall on the soil surface causes particles to rise and encourages sealing and encrustation. As a result, the infiltration rates fall and surface runoffs increase. These processes are most marked on severely sloping hillside land, as is the case, for example, for many Mediterranean vineyards. Furthermore, farmers of such land have given up traditional tilling and conservation methods in favour of mechanisation (Porta et al., 1994).

Table 3: Soil losses in vineyards with varying rainfall intensity

Region	Precipitation intensity (mm h^{-1})	Slope (°)	Erosion rate ($g\ m^{-2}\ h^{-1}$)
Theize (France)	60	9.6	112
La Rioja (Spain)**	70	3.4	45.2
Vaison la Romaine (France)***	100	6.8-7.8	252
La Rioja (Spain)**	104	5	93.2

* Gril *et al*. (2002); **Arnáez *et al*., (2007); ***Wainwright, (1996)

The generation of runoff and sediment production is high in vineyards, particularly those which experience high hourly precipitation intensity. Wainwright (1996) states that, with a rainfall intensity of 100 mm h-1 (22 September 1992), soil losses of 34 Mg ha-1 were recorded in south-east France (the Vaucluse and Drôme regions). Martínez-Casasnovas et al. (2005) note soil losses of 282 Mg ha-1 during a storm of an intensity of 187 mm h-1 in vineyards in the north-east of Spain (the Penedés region in Catalonia). Tropeano (1983) presents data for the north-west of Italy, concluding that vines are one of the crops with the highest level of soil losses. These figures tie in with the calculations of other researchers (Table 3).

In traditional cereal farming, too, erosion rates can be high in exceptional rainfall. De Alba et al. (1988) indicate that, during an isolated storm (70 mm of precipitation in barely 45 minutes) in Toledo (Spain), the soil loss rate was 48 times that of the annual average erosion rate and point out that such episodes may be responsible for more than 84% of annual losses. Similar phenomena can be found on abandoned cereal plantations, where there are serious problems controlling runoff, given the difficulty of plant colonisation in the Mediterranean region and the loose soil structure.

Precipitation of low and intermediate intensity has a less dramatic erosive effect. Where this occurs, the runoff effect can be controlled by the use of simple methods. On hillside vineyards, for example, contour ploughing could be carried out or cover crops planted. The application of fertiliser to the soil when cereal plots are abandoned produces a marked improvement in infiltration conditions and may well help new plant cover to grow (Lasanta et al., 1994).

5. Observations and Recommended Measures

Outlined above are the hydromorphological effects of certain changes to land use in the Mediterranean region. These changes will mean alterations in water availability in the future, when it is thought that overall precipitation will decline and become more irregular. We therefore need to apply sustainable measures that will rationalise water consumption and reduce soil losses through erosion.

In summary, these measures should be founded on four basic ideas: a) the exhaustive gathering of information relating to this problem; b) adequate territorial planning and management that reflects both supply and demand; c) the use of agricultural technology designed to save water and halt soil degradation; and d) increased awareness among the actors involved and consumers.

a. At present, information is available on water resources, erosion and the impact of land use and temporal and spatial changes to this use on the processes of desertification and environmental pollution in the Mediterranean region. A large number of research teams at universities and specialised centres are carrying out experimental work in basins and on slopes with differing plant cover and land use, aimed at determining water resources and erosion and runoff rates. They are also looking at the factors that play a direct or indirect role in the various hydromorphic processes and attempting to design models that will allow predictions to be made. Fostering this work and tackling new scientific challenges will ensure that suitable policies are applied in the short and medium term.

b. The organisation of water resources and soil conservation require an integrated planning and management system. This should be put in place for each drainage basin. Within basins, all the interrelated natural and anthropic factors should be considered as a whole. The basin is undoubtedly a spatial reference unit and should be managed by public bodies that deal with it in its entirety. Special attention should be paid to headwater basins, which are the source of the majority of surface water resources. Any intervention in these areas or changes to the use of land should be undertaken with caution, as there could be major repercussions in terms of runoff or increased flow. The interbasin transfer of water in order to balance out surpluses and deficits should be considered in the context of overall water management and in terms of sustainability and rational use. This is undeniably one of the best methods of securing social, economic and territorial cohesion. Any other measures, such as desalination, should be seen as an optional extra in view of the high economic and environmental costs.

c. Much of the irrigation infrastructure in the Mediterranean region is outdated and registers heavy water losses. Given the importance of irrigation for the agricultural economy of southern Europe, substantial improvements must be made to the current water distribution systems. It is also necessary to apply new techniques already employed in other arid and semi-arid regions that reduce water consumption. One such example is the replacement of border and spray irrigation by drip irrigation systems, which reduce water losses and the impact on the surface of the soil. It is essential for public authorities to be involved in this technological improvement and for there to be public and private investment in agricultural research, development and innovation.

In some regions, measures focused on improving existing irrigation systems through the use of such techniques may prove more worthwhile than expanding irrigation to new areas.

Soil erosion is a serious environmental problem, because it causes a loss of production capacity and restricts biodiversity. Soil erosion on Mediterranean farmland is linked to environmental factors (precipitation intensity and topography) and how farms are run (tillage systems and crop types). In most cases, this erosion is spread over a wide area and barely perceptible, but it presents a grave threat to the future of agricultural productivity.

Action is needed in the form of awareness campaigns, studies aimed at identifying better tillage systems and the promotion of soil conservation through investment and aid. By way of example, steps should be taken to prevent the expansion of farming on pronounced slopes in the direction of the sharpest incline, and the erosion process on recently abandoned land should be monitored.

d. Finally, the most effective way of ensuring the appropriate use of resources is to inform users. Publishing up-to-date knowledge of the causes and consequences of the improper use of water and soil degradation and methods of prevention will go a long way towards solving the problems in question.

Bibliography

- Alberto, F., Machín, J., Aragües, R., 'La problemática general de la salinidad en la Cuenca de Ebro'. In: *El Sistema Integrado del Ebro. Estudio Interdisciplinar.* Zaragoza, 1986, pp. 221-236.
- Arnáez, J., Lasanta, T., Ruiz-Flaño, P., Ortigosa, L., 'Factors affecting runoff and erosion under simulated rainfall in Mediterranean vineyards. *Soil & Tillage Research*, 93, 2007, pp. 324-334.
- Arnáez, J., Oserín, M., Ortigosa, L., Lasanta, T., 'Plant cover and land uses changes in the Northwestern Iberian Range (Los Cameros, La Rioja, Spain) between 1956 and 2001'. *B.A.G.E*, 47, 2008, pp. 195-211.
- Barberá, G., López Bermúdez, F., Romero Díaz, A., 'Cambios de uso del suelo y desertificación en el Mediterráneo: el caso del Sureste Ibérico'. In: *Acción humana y desertificación en ambientes mediterráneos* (García-Ruiz, J.M. and López García, (eds.)). CSIC, Zaragoza, 1997, pp. 9-39.
- De Alba, S., Benito, G., Pérez González, A. 'Erosión de suelos en episodios de lluvia de elevada intensidad versus episodios de moderada y baja intensidad y elevada frecuencia en ambientes semiáridos'. In: *Investigaciones recientes de la Geomorfología Española* (Gómez Ortiz, A. Salvador Franch, F., (eds.)), Sociedad Española de Geomorfología, Barcelona-Granada, 1998, pp. 483-492.
- De Santisteban, L.M., Casalí, J., López, J.J., 'Assessing soil erosion rates in cultivated areas of Navarre (Spain)'. *Earth Surf. Process. Landforms*, 31, 2006, pp. 487-506.
- Dwyer, J., coord., *'The Environmental Impacts of Irrigation in the European Union'*. A report to the Environment Directorate of the European Commission, Brussels, 2000, pp. 1-138.
- Eurostat, 'Europe in figures – Eurostat Yearbook 2008'. Office for Official Publications of the European Communities, Luxembourg, 2008, pp. 1-566
- Frutos, L.M., 'Los cambios de la agricultura de regadío aragonesa (1950-1980)'. In: *Medio siglo de cambios agrícolas en España.* (Gil Olcina, A., Morales Gil, A., (eds.)). Instituto de Cultura Juan Gil-Albert. Diputación General de Alicante, Alicante, 1993, pp. 771-803.
- Gallart, F., Clotet, N., 'Some aspects of the geomorphic processes triggered by an extreme rainfall event: the November 1982 flood in the eastern Pyrenees'. *Catena Suppl.*, 13, 1988, pp. 79-95.
- Gallart, F., Llorens, P., 'El papel de los cultivos de montaña y su abandono en la economía del agua'. In: *Efectos geomorfológicos del abandono de tierras* (García Ruiz, J.M., Lasanta, T., (eds.)). Sociedad Española de Geomorfología, Zaragoza, 1994, pp. 43-55.
- Gallart, F., Llorens, P., 'Water resources and environmental change in Spain. A key issue for sustainable integrated catchment management'. In: *Environmental change and water sustainability* (García-Ruiz, J.M., Jones, J.A.A., Arnáez, J. (eds.)). Consejo Superior de Investigaciones Científicas, Zaragoza, 2002, pp. 11-20
- García Ruiz, J.M., 'Marginación de tierras y erosión en áreas de montaña'. En: *Erosión y recuperación de tierras en áreas marginales* (Lasanta, T., García Ruiz, J.M., (eds.)). Instituto de Estudios Riojanos, Logroño, 1996, pp. 33-50

- García Ruiz, J.M., White, S.M., Martí, C., Valero, B., Paz Errea, M.P., Gómez-Villar, A. *'La catástrofe del barranco de Arás (Biescas, Pirineo Aragonés) y su contexto espacio-temporal'.* Instituto Pirenaico de Ecología, Zaragoza, 1996, pp. 1-54.
- García Ruiz, J.M., Beguería, S., López, J.I., Lorente, A., Seeger, M. (2001*). 'Los recursos hídricos superficiales del Pirineo aragonés y su evolución reciente'*. Geoforma Ediciones, Logroño, 2001, pp. 1-192.
- Giordano, A., 'A first approximation of soil erosion risk assessment in the southern countries of the European Community'. *Erosion assessment and modelling* (Morgan, R.P.C., R.J. Rickson, (eds.)). Commission of the European Communities Report EUR 10860, 1986, pp. 3-24.
- IPCC, IPCC, 2007: Climate Change 2007: Synthesis Report. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (Core Writing Team, Pachauri, R.K and Reisinger, A.(eds.)). IPCC, Geneva, Switzerland, pp. 1-104.
- Gril, J.J., Canler, J.P., Carsoulle, J., 1989. 'The benefit of permanent grass and mulching for limiting runoff and erosion in vineyards; experiments using rainfall simulations in the Beaujolais'. In: *Soil Erosion Protection Measures in Europe* (Schwertmann, U., Rickson, R.J., Auerswald, K., (eds.)), Catena-Verlag, Freising, Germany, 1989, pp. 157-166.
- Koluvek, P.K., Tanji, K.K., Trout, T.J., 'Overview of Soil Erosion from Irrigation'. *Journal of Irrigation and Drainage Research,*119 (6), 1993, pp. 9-29.
- Lana-Renault, M. '*Respuesta hidrológica y sedimentológica en una cuenca de montaña media afectada por cambios de cubierta vegetal. La cuenca experimental de Arnás, Pirineo central*'. Doctoral thesis. Universidad de Zaragoza, 2007, pp. 1-314.
- Lasanta, T., Pérez-Rontomé, M.C. García Ruiz, J.M., 'Efectos hidromorfológicos de diferentes alternativas de retirada de tierras en ambientes semiáridos de la Depresión del Ebro'. In: *Efectos geomorfológicos del abandono de tierras* (García Ruiz, J.M., Lasanta, T., (eds.)). Sociedad Española de Geomorfología, Zaragoza, 1994, pp. 70-82.
- Lasanta, T., 'El proceso de marginación de tierras en España'. In: *Erosión y Recuperación de Tierras Marginales* (Lasanta, T. and García Ruiz, J.M., (eds.)). Sociedad Española de Geomorfología, Logroño, 1996, pp. 9-31.
- Lasanta, T., Pérez Rontomé, M.C., Machín, J., Navas, A, Mosch, W., Maestro, M. 'La exportación de solutos en un polígono de regadío de Bardenas (Zaragoza)'. *Cuaternario y Geomorfología*, 15, 2001, pp. 51-66.
- López Bermúdez, F., Romero-Díaz, M.A., 'Génesis y consecuencias erosivas de las lluvias de alta intensidad en la región mediterránea'. *Cuadernos de Investigación Geográfica*, 18-19, 1993, pp. 7-28.
- Llorens, P., Latron, J., Gallart, F., 'Analysis of the role of agricultural abandoned terraces on the hydrology and sediment dynamics in a small mountainous basin' (High Llobregat, Eastern Pyrenees)'. *Pirineos,* 139, 1992, pp. 27-46.
- MacDonald, D, Crabtree, J.R., Wiesinger, G., Dax, T., Stamou, N., Fleury, P., Gutiérrez Lazpita, J., Gibon, A. 'Agricultural abandonment in mountain areas of Europe: Environmental consequences and policy response' *Journal of Environmental Management* 59, 2000, pp. 47-69.
- Martínez-Casasnovas, J.A., Ramos, M.C., Ribes-Dasi, M., 'On-site effects of concentrated flow erosion in vineyard fields: some economic implications'. *Catena,* 60, 2005, pp. 129-146.

- Mateos, L., Guiráldez, J. V., 2005., 'Suspended load and bed load in irrigation furrows'. *Catena*, 64, 2005, pp. 232-246.
- Ortigosa, L., Oserín, M., Arnáez, J., 'Comportamiento geomorfológico del espacio agrario abancalado en Camero Viejo (Sistema Ibérico): resultados de una modelización territorial'. In: *Efectos Geomorfológicos de Campos Abandonados* (García Ruiz, J.M., Lasanta, T. (eds.)). Sociedad Española de Geomorfología, Zaragoza, 1994, pp. 121-134.
- Ortigosa, L, García Ruiz, J.M. (1995) 'Geomorphological consequences of afforestation at a basin scale. An example from the Central Pyrenees'. *Physics and Chemistry of the Earth*, 20 (3-4), 1995, pp. 345-350.
- Oserín, M. *'Cambios en la gestión del territorio de una montaña media mediterránea y sus impactos ambientales. Hacia un nuevo paisaje: altos valles del Iregua, Leza, Jubera y Cidacos, Sistema Ibérico Noroccidental'*. Servicio de Publicaciones de la Universidad de La Rioja , Logroño, 2007, pp. 1-355.
- Porta, J., Ramos, J.C., Boixadera, J., 'Mechanical measures for runoff management and erosion control in the vineyards of northeast Spain'. In: *Conserving Soil Resources: European Perspective* (Rickson, R.J., (ed.)), CAB International, Wallingford, 1994, pp. 369-378.
- Poesen, J.W.A., Hooke, J.M. 'Erosion, flooding and channel management in Mediterranean environments of southern Europe'. *Progress in Physical Geography*, 21 (2), 1997, pp. 157-199.
- Rico Amorós, A., 'Políticas agrarias, eficiencia socioeconómica y retos de futuro en los regadíos intensivos'. *Boletín de la AGE*, 41, 2006, pp. 113-149.
- Ruiz Flaño, P. *'Procesos de erosión en campos abandonados del Pirineo'.* Geoforma Ediciones. Logroño, 1993, pp. 1-191.
- Tropeano, D., 'Soil erosion on vineyards in the Tertiary Piedmontese basin (northwestern Italy): studies on experimental areas'. *Catena Supplement*, 4, 1983, pp. 115-127.
- Wainwright, J., 'Infiltration, runoff and erosion characteristics of agricultural land in extreme storm event, SE France'. *Catena*, 26, 1996, pp. 27-47.

3. Actions to Protect and Restore Agro-Ecosystems: Soil Issues

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CONTENTS

Abbreviations

SPS	Single Payment Scheme
CAP	Common agricultural policy
CoGAP	Codes of Good Agricultural Practice
COM	European Commission
DESERTLINKS	Combating Desertification in Mediterranean Europe: Linking Science with Stakeholders
DESIRE	Desertification mitigation and remediation of land – a global approach for local solutions
MEDACTION	Policies for land use to combat desertification
MEDALUS	Mediterranean Desertification and Land Use
MEDRAP	Concerted action to support the northern Mediterranean regional action programme to combat desertification
UNCCD	United Nations Convention to Combat Desertification
UNEP	United Nations Environment Programme

Executive Summary

Soil is one of the most important elements of the Earth's ecosystems, because it exerts an influence over the growth of vegetation and, more generally, over the preservation of life – land life, at least – on our planet. It is classed as a non-renewable natural resource on which the economy depends at local and global level. Protection of the soil is therefore of primary concern for mankind, in the interests of the survival and development of modern societies. The larger the earth's population, the greater the need for correct use and protection of agro-ecosystems, including soils. Soil is described as a 'living' organism; it is a natural, open system which affects and is affected by the environment. In other words, there is a dynamic energy balance between the soil and the environment.

Since the mid-20th century, the mechanisation of agriculture has contributed significantly to the degradation of agricultural land. Favourable soil and climatic conditions and the availability of surface and groundwater have led to intensive soil cultivation, with an adverse impact on the wider agro-ecosystems. Lowland areas with very productive soils have been adversely affected by the accumulation of salts and other toxic substances, by degradation of the organic material and the structure of the soil, and by inert materials covering the soil. Soils on slopes have been eroded at much faster rates than in previous decades when traditional farming methods were used and the result has been a reduction or loss of their productivity. Biodiversity and vegetation growth have in many cases been adversely affected, with the result that large areas are being abandoned because agriculture is no longer economically viable. Many areas of Greece, and Mediterranean Europe generally, have suffered environmental degradation and, with the added burden of climate change, have become desertified. The restoration of agro-ecosystems or containment of further soil degradation is a pressing need for our society. The European Commission, recognising the need to preserve soils and restore ecosystems, is preparing a directive on soil protection, covering the most significant threats of land degradation.

The measures taken to protect agro-ecosystems must address the issue of agricultural soil degradation in a comprehensive manner: firstly, in terms of farming practices, by proposing a reduction in mechanical tilling and the preservation of plant cover, protection of existing berms, and incorporation of vegetable waste; and secondly, in terms of the agricultural sector's economic policy and land uses, by subsidising fallow land, reducing tax for producers who respect the environment, removing areas with deficient soils from cultivation, defining the boundaries of productive farmland, and transferring knowledge and technology to land users.

Introduction

The main environmental risks associated with soil degradation, and hence the degradation of agro-ecosystems, are linked with the following processes: erosion, salinisation/alkalinisation, loss of organic matter, chemical pollution, degradation of biodiversity, compaction, inert materials covering the soil, and desertification of the land. Soil erosion, and especially accelerated erosion due to human intervention, leads to disruption or loss of one or more functions of the soil system. The factors which usually lead to accelerated erosion are depletion of the natural vegetation and particularly forests, changes in farming techniques, overgrazing, catastrophic fires, soil levelling and the cultivation of land with very steep gradients. The salinisation of soils is a process which leads to the concentration of considerable amounts of water-soluble salts in the soil body, as a result of the upward movement of groundwater due to evapotranspiration or irrigation with poor-quality water. The organic matter content of the soil reflects a dynamic balance between the influx of vegetation and the decomposition of organic matter by soil microorganisms. The reduction of the organic matter content is an aspect of land degradation which has a significant influence on soil erosion. The intensification of agriculture and catastrophic fires drastically reduce the organic matter content of soils. Soil pollution may be caused either across large areas by diffusion of atmospheric pollutants, or on a restricted local scale as a result of industrial activity and the application of fertilisers and plant protection products. Soil biodiversity varies considerably between different soil types and is directly linked with the functionality of the soil system. Soil compaction is a phenomenon associated with a reduction in the gaseous phase of the soil, resulting in disruption or loss of certain soil functions. It is caused by external forces exerted on the surface, due to stock-rearing or the use of farm machinery. As regards the covering of the soil by inert materials, this clearly goes hand in hand with the expansion of urban areas and related infrastructures, disrupting water percolation and the dynamic balance between the gaseous phase of the soil and the atmosphere. The last of the above-mentioned environmental threats, desertification, is defined – according to the internationally accepted scientific definition – as land degradation in arid, semi-arid and dry sub-humid areas resulting from various factors, including climatic variations and human activities (World Summit on the Environment, 1992).

These threats are affected by various driving forces and pressures which lead to the degradation of agricultural ecosystems. The various agro-ecosystems are subject to a range of degradation risks linked with the type and intensity of the threat. To limit soil degradation in agricultural areas and prevent a future deterioration of the situation, it is crucially important to effect an immediate changeover to farming techniques and natural resource management practices which are effective against the degradation of agricultural ecosystems. This paper attempts to document and analyse the main farming and management methods used to combat the degradation of agro-ecosystems, with an examination of the subject from the point of view of agricultural soils.

1. The European Institutional Framework for Combating Soil Degradation in Agricultural Areas

The European Union today has the institutional guarantees, the scientific base and the technological achievements which can lay the groundwork for planning and implementing an integrated strategy against the risk of degradation of agricultural soils.

Research in the relevant areas has been under way for many years, and its results have been tested and are safe for use on a wide scale. These results have led the European Union to adopt regulations and directives which aim to maintain and improve agricultural production while at the same time protecting natural resources. In June 2003, agriculture ministers adopted a fundamental reform of the common agricultural policy (CAP). This reform completely changed the way in which the EU provided financial support for the agricultural sector. As we know, under the new CAP, the decoupled Single Payment Scheme (SPS) replaced most existing crop and livestock payments as from 1 January 2005. The new scheme decouples payments from production and sets strict requirements and rules for maintaining the land in good agricultural and environmental condition (Codes of Good Agricultural Practice – CoGAP), and also for compliance with a range of legal commitments regarding the environment, public health, the health of plant and animal resources, the identification/traceability of animal resources, and animal welfare. All these requirements, which must be observed by any producer wishing to qualify for the SPS, are included under the heading of 'cross-compliance'. For example, the CoGAP soil standards include rules for the good management of soil resources, such as limiting erosion of agricultural land and maintaining the organic matter content and good structure of soils. In addition to the rules of cross-compliance, which are directly linked with the decoupled SPS, there are, of course, various measures in force under the Rural Development Programme which are proving extremely effective against the degradation of agricultural ecosystems due to soil degradation. Obvious examples are the set-aside of agricultural land, extensification of cattle farming, and reafforestation of agricultural and non-agricultural land.

The existing institutional framework needs appropriate scientific support, both on specialised technical matters and on questions of communication with the producers concerned. With this support, the introduction of rules to combat the environmental degradation of agro-ecosystems, and the adoption and implementation of measures by producers, will become more effective. It is therefore crucially important that the scientific community should link up with technical experts and the legislating institutions (European Commission, ministries, local authorities), so that the environmental condition of agricultural land can be monitored and the legislation can be immediately reformed and updated where necessary. The systematic documentation of the measures which can be implemented or the farming techniques which must be avoided in order to combat the degradation of soil resources in agricultural areas: these are the concerns of this paper, which can be regarded as a small contribution in this direction.

2. Management of Environmental Risks Associated With Soil Degradation

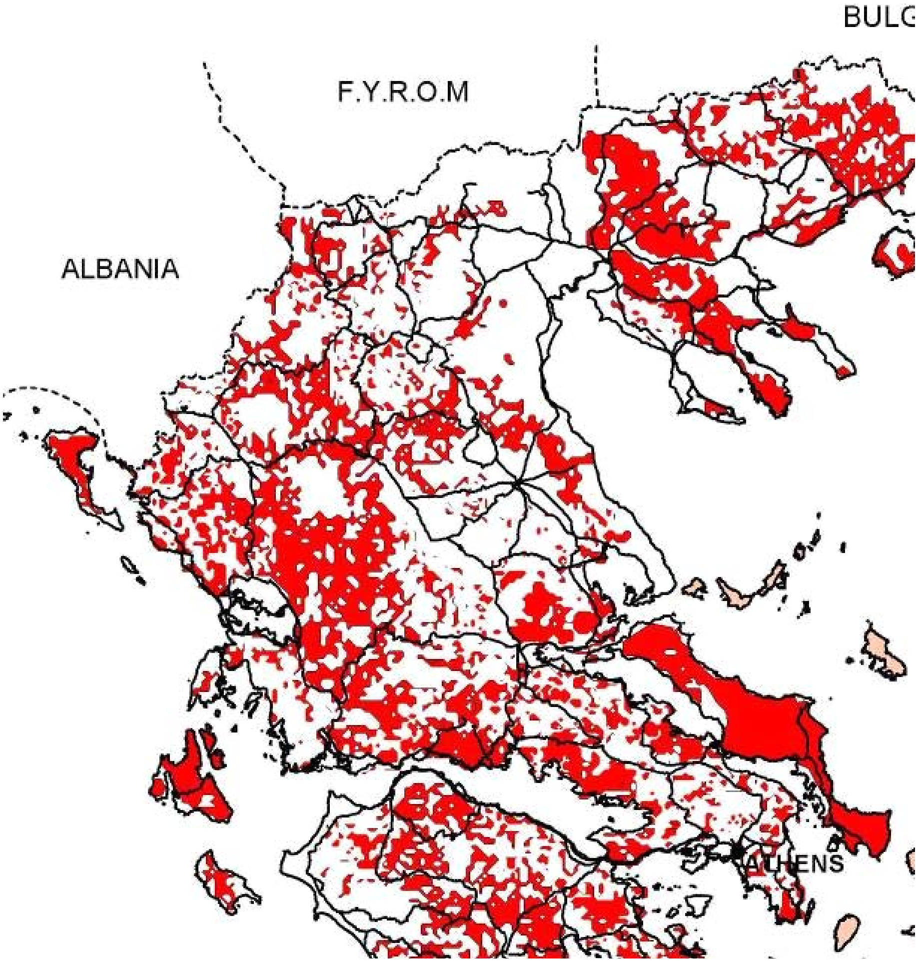
2.1. Risk Due to Soil Erosion

El-Swaify (1994) estimates that of the roughly 2 billion hectares of severely degraded soil around the world, roughly 55% is due to erosion. The erosion of soil is classed as water, mechanical or wind erosion. Water erosion is caused by water running off the soil surface after heavy rain and carrying soil particles with it. Water erosion of the soil is a natural phenomenon which usually progresses at slow, non-dangerous rates. However, human interference with vegetation may disastrously accelerate the process. Vegetation and land use are important factors which determine the frequency of surface runoff and soil erosion (Bryan and Campbell, 1986; Mitchell, 1990). Large-scale deforestation, intensive cultivation of the soil, overgrazing, the burning of pastureland to renew biomass production, the planting of slopes with olive trees, vines and cereals in places where the soil surface remains exposed during the season of heaviest rainfall, all lead to faster rates of water erosion. The proportion of plant cover is reduced to such an extent that raindrops strike the soil with great force, dislodging soil particles which then clog the waterways so that water accumulates on the surface, with resulting runoff and soil erosion (Faulkner, 1990).

In Greece, the topographic relief (long, steep gradients), the semi-arid climate with long periods of drought alternating with periods of heavy rainfall, the partial plant cover in some areas, and intense human intervention in natural resources create conditions conducive to soil erosion (Fig. 1).

Mechanical erosion is the result of soil cultivation and occurs when the soil is ploughed or disc-harrowed. The soil is shifted in the direction of movement of the tractor. According to many specialists (Quine et al., 1994; Govers et al., 1996; Quine et al., 1997; Lobb et al., 1995, Kosmas et al., 2001), the displacement of soil in hilly areas due to its mechanical treatment may exceed the displacement caused by runoff water. During mechanical treatment of the soil, the surface soil material is gradually shifted downhill. The result of this process is a reduction in soil depth on the upper and intermediate parts of the hillside, and an increase on the lower parts. Indeed, it has been shown that mechanical processing of the soil may increase the water erosion of the soil even on slight gradients (Smith and Stamey, 1965).

Fig. 1. High-risk areas for water and wind erosion in Greece, assessed on the basis of the PESERA soil erosion model



Studies carried out in hilly areas of Attica, Viotia and Thessaly by the Agricultural University of Athens (Kosmas et al., 2001, Gerontidis et al., 2001, Tsara et al., 2001) have shown that soil displacement is affected by the depth of ploughing, the direction of ploughing, the gradient of the soil surface and the type of agricultural implement. Water erosion in areas planted with cereals, vines or olives is usually responsible for an annual soil loss of a few millimetres (1-3 mm) or less (Kosmas et al., 1996). The measured annual soil loss in the same areas when cultivated mainly with cereals varies between 4 and 14 mm annually (Kosmas et al., 2000). Measurements in Thessaly showed that the soil depth has decreased by 24-30 cm over a period of 63 years.
The methods of combating mechanical erosion are can be summarised as follows:

- Ploughing on sloping land, where the gradient permits, should be carried out parallel to the contour lines, not parallel to the gradient. The use of a mounted half-turn plough is advisable, and the soil should be turned in an upward direction.
- A reduction in ploughing speed and depth contributes towards reducing mechanical erosion on sloping land.
- Ploughing should preferably be carried out three times in an uphill direction and once in a downhill direction to equalise the soil loss.
- A cultivator is more suitable for use on sloping land than other tilling implements.

Wind erosion is due to the action of the wind, which carries soil particles over various distances according to the size of the soil grains and the wind force. The orientation of exposure of the gradient affects wind erosion. Southerly winds usually blow during the wet season, when soils are relatively moist and are protected by natural plant cover. Areas which are exposed to the south and south-west are therefore less affected by wind erosion. Areas exposed to the north, on the other hand, are vulnerable to wind erosion, because the northerly winds, which also blow during the summer period, act on soil which is dry and likely to have no plant cover, causing wind erosion. The lack of soil water observed in summer and early autumn creates favourable conditions for detachment of soil particles and wind erosion. Animal track-ways are also vulnerable to wind erosion. An animal, as it moves across the ground, pulverises the soil with its hooves, leaving a layer of dust which is easily carried away by the wind. Practical measures to combat wind erosion include the maintenance of adequate plant cover in vulnerable areas in order to retain soil particles so that they are not carried away by wind action.

2.2. Risk Due to Salinisation/Alkalinisation of the Soil

Salinisation and alkalinisation are the main chemical processes causing desertification under semi-arid and arid climatic conditions, especially on flat terrain. It is estimated that approximately 30% of all the cultivated land in the world (Rengasamy, 1998) has been desertified as a result of this process. Soil salinisation is an increasingly common phenomenon around the world, and it affects millions of hectares throughout Europe. The term 'salinisation' refers to the process of accumulation of water-soluble salts in the soil. In the process of salinisation, the rate of water uptake by crops is greater than the rate of salt uptake, so that salts accumulate in the soil. Irrigation with water containing high concentrations of salt may cause a tenfold reduction in the rate of percolation (Imeson and Verstraten, 1989). According to Szabolks (1989), secondary salinisation is responsible for the abandonment of roughly 10 million hectares a year, and Epstein (1976) estimates that of the total area of irrigated soils in the world, which is calculated at 2 300 x 106 x 1 000 m3, approximately a third has been converted into saline soils. The increase in salt levels in the upper surface soil layers may have a negative impact on plant growth and crop yield, to the point where it destroys the plants. High concentrations of various salts (e.g. sodium chloride, magnesium sulphate, calcium sulphate and bicarbonate salts) affect plant growth directly due to their toxicity, but also indirectly by increasing the dynamics of osmosis and reducing water uptake by the roots. The three main processes which are likely to cause salinisation are:

- a rise in the water level to the surface or near the surface of the soil;
- over-use of water for irrigation in dry climates with clay soils;
- infiltration of seawater into coastal water tables due to over-extraction of groundwater.

The first of these processes occurs on alluvial plains or in depressions in semi-arid regions, when the water table is close to the soil surface. The capillary upward movement of water causes an accumulation of salts, following evaporation of the water due to intense solar radiation (Fig. 2). In soils of this type, it is often observed that the salts form a surface crust. The second process occurs in cultivated areas, where irrigation is associated with high levels of evaporation and the soil is of clayey granulometric composition. In this case, the leaching of salts by rainwater is limited, and ions of sodium chloride and calcium chloride accumulate in the surface layers of the soil. The last of the above processes occurs in coastal regions, where over-extraction of water, due to multiple needs, causes a drop in water level and an influx of seawater.

In addition to the three main processes mentioned above, salinisation may occur in particular areas as a result of other natural or anthropogenic causes. Farming practices such as over-use of fertilisers, especially on a long-term basis, may contribute to increased

ionic concentration of the soil solution, and incorrect use of machines may cause soil compaction, resulting in inadequate drainage conditions. The causes may be various, but the end result is the accumulation of salts on the surface of the arable soil (0-40 cm), which reduces the ability of crops to take up water and concentrates ions which are toxic to plants.

Fig. 2. Soil salinisation due to poor drainage conditions (left) and irrigation with poor-quality water (right)

One of the main causes of secondary salinisation today is the use of brackish water for irrigation, due to infiltration of seawater into aquifers. Saline contamination of groundwater is a serious and steadily increasing problem for all coastal regions in Europe. Irrigation may lead to an accumulation of inorganic salts in the soil due to evaporation. This means that irrigation may be a factor leading to a loss of farming potential of the soil. Groundwater is encountered mainly in alluvial fields along coasts or in valleys. The water from these underground aquifers is used intensively for irrigating summer crops, with adverse consequences for the soil because of the infiltration of seawater. In addition, the increase in tourism over the past 40 years has had a serious impact on the environment, and particularly on the distribution of land uses and water resources. The present tendency towards a hotter and drier climate has increased the damage to crops due to drought. Irrigation has been extended to large areas for more efficient agriculture, in order meet increased demands for food and raw materials. The problem of salinisation has become more severe because of the reduced renewal of groundwater, due to reduced rainfall and the infiltration of brackish water into aquifers. Agriculture takes the largest share of the water extracted and consumed, especially in the coastal regions of the Mediterranean, where there is intensive irrigated vegetable cultivation. In many regions, however, the sectors which have contributed significantly to the over-exploitation of water tables are industry, urban development and seasonal tourism.

Typical management measures to protect areas against salinisation are the implementation of surface drainage and irrigation with good-quality water. Surface drainage is achieved by constructing drainage ditches. Groundwater enrichment is another practice used to improve the quality of groundwater and prevent soil salinisation. The Greek National Action Plan against Desertification brings together the following actions to protect soils against salinisation:

- periodic quality control of irrigation water;
- periodic monitoring of soluble salts in soils to determine soil salinity;
- adequate drainage of irrigated soils, with the construction of drainage networks;
- irrigation of soils with surplus water to provide plants with the amount needed for their normal growth, and to wash out soluble salts (especially where the irrigation water is of poor quality);

- constant monitoring of the upward movement of soluble salts from the lower soil horizons where these contain a high proportion of salts due to irrigation;
- strict control of the pumping of water from aquifers which come into contact with seawater, to avoid infiltration of brackish water.

2.3. Risk due to Loss of Organic Soil Matter

Organic matter in the soil is a very important indicator of soil quality for the agricultural sector (productivity, agricultural income) and for the environmental sector (carbon storage reservoir). It plays a crucial role in the biological activity of the soil. The quantity, biodiversity and activity of the soil fauna and microorganisms are directly related to the organic matter content. Organic matter and the biological activity it generates have important effects on the physical and chemical properties of soils. The aggregation of soil particles, and hence the stability of soil structure, increases with the organic matter content of the soil. This also results in an increase in the water percolation rate and in the quantity of water available for plants, while at the same time protecting the soil against water and wind erosion. The organic matter content also improves the dynamic balance of the soil solution, making basic nutrients more available.

Apart from climatic factors (primarily temperature), the main processes causing loss of organic matter are soil erosion and mineralisation. The development of the agricultural sector has certainly resulted in serious losses in the quantity of organic soil matter, as a consequence of certain farming techniques and practices. For example, erosion of the surface layer of soils leads to serious losses of organic matter, because most of the organic matter is contained in that layer. Erosion of the surface layer of soils may be caused by unsuitable ploughing which destroys the structure, or by runoff water, or by a reduction in plant cover. According to scientific studies, soil losses due to erosion amount to a worldwide total of 150 to 1 500 million tonnes a year (Lal, 1995; Gregorich et al., 1998). More recent data (Balesdent et al., 2000) show that ploughing plays a pre-eminent role in the destabilisation of soil macro- and micro-aggregates and consequently in the loss of the organic matter contained in them. The conclusion drawn is that farming techniques relying on ploughing have caused a reduction in the organic matter in agricultural land, especially in Europe, and a release of carbon dioxide, which is associated with the greenhouse effect and climate change. It is common practice among many producers to destroy the plant residues of the previous crops by 'stubble burning'. This practice is seen as destructive human intervention, in terms of the organic matter content of soils, because decomposing plant or animal residues are burnt together with the stalks. It is obvious, of course, that large, catastrophic fires cause even greater problems of reduction of soil organic matter (Fig. 3).

Fig. 3. Burnt land in the Eyialia region, resulting in soil erosion and loss of organic matter

The reduction in organic matter is of particular significance for European soils. According to the European Soil Bureau, and on the basis of the limited amount of data, nearly 75% of the total area of soil examined in southern Europe contains a low (3.4%) or very low (1.7%) percentage of organic matter. Agriculturalists consider that soils with less than 1.7% organic matter are at the initial stage of desertification. The European Commission, in its report 'Towards a Thematic Strategy for Soil Protection' (COM(2002) 179 final), highlights the decline in organic matter in the soils of Mediterranean Europe, which is a significant threat to soil resources.

There are various approaches to managing agricultural soils with a view to increasing their organic matter content, with the primary aim of increasing the plant biomass (choice of varieties, appropriate fertilisation and irrigation). The principal methods of increasing organic matter in soils are based on sustainable agriculture, including zero-tillage or minimum-tillage techniques and the retention of plant cover (living or dead plant fibre) on the soil surface for the greater part of the year. The literature records a number of other strategies for increasing organic matter in soils, such as the application of soil additives (manure, crop residues, etc.), plant cover with plants which develop a deep root system, and appropriately chosen crop rotations.

2.4. Risk Due to Chemical Pollution of the Soil

Chemical pollution means pollution of the soil with toxic substances which limit the spread of flora and fauna. Contamination of soil ecosystems with various pollutants (heavy metals, organic substances, radioactive elements) has increased considerably in recent years in many regions of the world. In many countries industrialisation has led to soil pollution.

In soil pollution, a distinction is drawn between pollution from identified point sources and pollution from diffuse sources. Pollution from identified point sources is in most cases associated with mining activity, industrial installations and landfills. Diffuse pollution is associated with atmospheric fallout and certain agricultural practices.

With gas emissions and waste from industrial installations, dangerous toxic substances have been added to soils. These substances are transferred from the soil to plants and then via the food chain to animals and humans, returning to the soil in waste material. In the case of mining activity, the risks are associated with the storage or disposal of residues. One of the most notorious cases of soil pollution with adverse effects on public health occurred in the Toyama region of Japan in 1912. At that time, various mineral companies operating in the mountains of the region were discharging their waste, which contained cadmium, into rivers, polluting the water and soils and causing itai-itai disease in a large proportion of the local population. This disease affects kidney function and bone hardness, and causes unbearable pain. Seepage from landfills may end up in the surrounding soil and in other materials, so that ultimately it is diffused into groundwater and surface water.

Atmospheric fallout is due to emissions from industry, vehicular traffic and agriculture. Fallout of airborne pollutants results in a build-up in the soil of pollutants which cause acidification (e.g. SO2, NH4), heavy metals (e.g. cadmium, lead, arsenic, mercury) and many organic compounds (e.g. dioxins). Intensive farming with the systematic use of commercial phosphate fertilisers adds small quantities of cadmium to the soil. Deposits of ammonia and other nitrogen compounds (due to emissions from agriculture, vehicular traffic and industry) cause unwanted nitrogen enrichment of the soil, resulting in reduced biodiversity. Production systems which do not achieve a balance between incoming and outgoing substances lead to a nutrient imbalance in the soil, which often results in pollution of groundwater and surface water. The application of nitrate fertilisers under unfavourable soil and climatic conditions may cause toxic effects in humans and animals. Another substance which may have dangerous and harmful effects is fluorine. This element is associated partly with volcanic activity and partly with industrial pollution. For example, in Africa and Iceland, significant concentrations of fluorine have been observed in soils near

volcanoes, and harmful pollution due to the same element has been observed in soils near ore industries in Norway. The plant-protection substances used in agriculture often create soil pollution problems. Most of the pesticides found in conventional agriculture are toxic compounds used to combat plant diseases and weeds. When they are not used judiciously and codes of good farming practice are not followed, they may remain in the soil and leach into the groundwater, or may vaporise and affect biodiversity or enter the food chain.

2.5. Risk Due to Degradation of Soil Biodiversity

The greatest quantity and variety of life forms are found in the soil. In meadowland, for every 1 to 1.5 tonnes of biomass living on the soil (livestock and grass), roughly 25 tonnes of biomass (bacteria, earthworms, etc.) are concentrated in the top 30 cm of soil. Soil flora and fauna play a crucial role in various functions of the ecosystem which are very beneficial and useful to human communities.

'Biodiversity' refers to the variety of living organisms found in a particular environment or, on a global scale, on the planet. Soil biodiversity is generally defined as the variability of living organisms in soil and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems (UNEP, 1992). Some basic functions performed by soil flora and fauna are the release of nutrients from the organic matter, the formation and maintenance of good soil structure, and the effective storage and movement of water in the soil. Soil bacteria, fungi, protozoa and other small organisms play an essential role in maintaining the physical and biochemical properties needed for soil fertility. Larger organisms, such as worms, snails and small arthropods break up organic matter, which is further degraded by microorganisms so that it is dispersed to progressively deeper layers of the soil, where it becomes more stable. Furthermore, soil organisms themselves serve as reservoirs of nutrients, suppress external pathogens and break down pollutants into simpler, often less harmful components.

Degradation of soil biodiversity is defined as a reduction in the variety and quantity of life forms living in soil. Increasing pollution, climate changes which cause desertification and forest depletion, and the development of increasingly intensified and industrialised agricultural models of food production: these are all risks to global biodiversity, which is being steadily impoverished and is moving very fast towards a state of 'biological homogenisation'. The dynamic interaction between the living organisms of the soil and human interventions is not fully understood. However, there are sufficient data and evidence to show that biological activity in the soil depends on the organic matter content, the chemical properties of the soil (e.g. the presence of pollutants or salts), and physical properties such as porosity, which in turn is affected by compaction or covering of the soil. Inappropriate use of plant-protection substances, particularly nematicides, can have very negative effects because of their poor selectivity. Individual studies indicate that some herbicides suppress the activity of bacteria and fungi. Moreover, excessive use of nutrients can drastically alter the biological balance and thus reduce soil biodiversity.

As the foregoing makes clear, living organisms and their activity are particularly important in most soil functions, and their suppression by human action has crucial implications for the sustainability of soil resources. Sound management of soil resources, which helps to provide protection against erosion, salinisation, pollution and desertification, and also to increase the amount of organic matter, contributes towards the protection of soil biodiversity.

2.6. Risk Due to Soil Compaction

Soil compaction is a type of physical degradation whereby the biological activity of the soil and the productivity of agro-ecosystems are reduced as a result of impaired ability to percolate water and increased vulnerability to soil erosion. Any agricultural machine moving across a field exerts two types of pressure on the soil: pressure affecting the volume of the

soil, and pressure affecting soil adhesion. Pressure affecting the volume of the soil leads to increased soil density (compaction) while the uniformity of the soil structure characteristics remains unchanged, provided the pressure is distributed uniformly over the surface. Pressure affecting adhesion, on the other hand, causes the soil layers to shift in relation to each other. Mechanical pressure exerted on soils by agricultural machinery affects plant growth directly and indirectly by modifying the physical properties of the soil. When mechanical pressure is applied to the soil, pressure affecting the soil volume is predominant and accounts for 90% of the total pressure exerted. Its main effects are a change of soil pore volume (reduction of the gaseous phase) and reduction of the water percolation rate (Fig. 4). When heavy rainfall occurs and the water percolation rate is reduced due to compaction, large quantities of water are not absorbed and they intensify the risk of erosion. Pressure affecting adhesion contributes to a change in structure of the solid-phase aggregations and mechanical damage to the root systems of plants.

Fig. 4. Change in porosity of the subsurface layer of the soil due to compaction by agricultural machinery

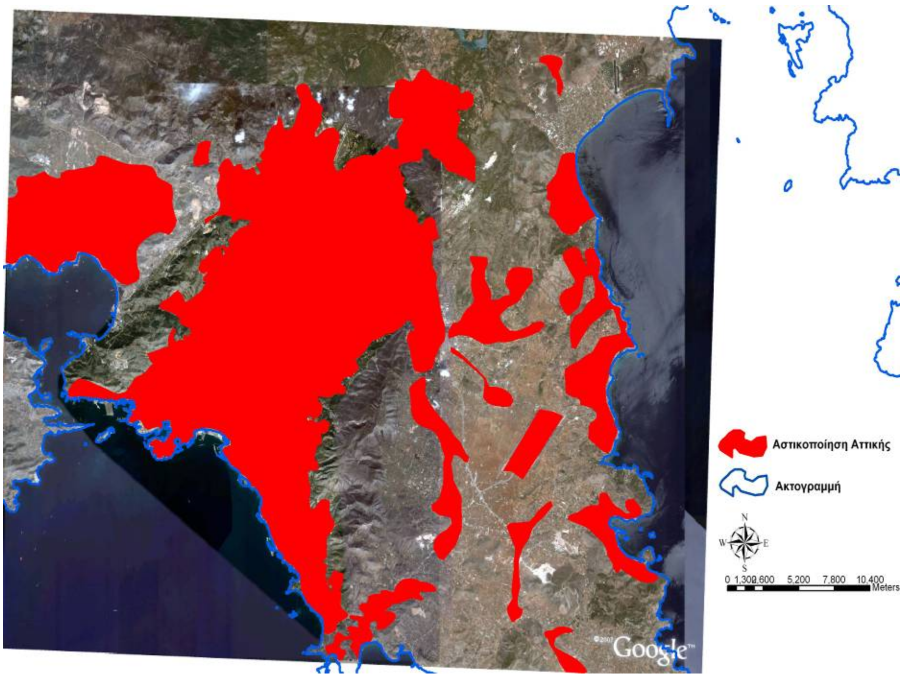
The process of soil compaction represents the relationship between the change of density and the pressure exerted for a specific percentage of soil moisture. Soil compaction diminishes with a reduction in soil moisture (Konstankiewicz, 1977; Lawrence, 1978). The pressure exerted by modern tractors on agricultural soils is considerable, and depends mainly on their weight, the contact surface between wheel and soil, and the tyre pressure. Another significant factor influencing changes in soil density is the speed at which the agricultural machine moves. It has been found in scientific studies that an increase in wheel speed causes a reduction in the magnitude and width of soil density changes (Karczewski, 1978). Changes in soil density determine other basic physical properties affecting plant growth, such as resistance to penetration. An increase in penetration resistance causes a reduction in the length of the root systems of plants per unit of soil area. The effect of the type of soil, physical properties of the dry phase of the soil, and compaction on the water retention capacity and hydraulic properties of soils is also considerable. An increase in soil compaction is always accompanied by a reduction in the water content of the soil.

It is also worth noting that subsidence in organic soils is significantly affected by the compaction process. The term 'subsidence' is used to describe the degradation of organic soils. Specifically, the factors which contribute to the subsidence of the subsurface organic layers below the water table are mainly due to compaction caused by the frequent passage of heavy agricultural machines. Another practice in agro-ecosystems which plays a part in soil compaction, and hence soil degradation, is intensive grazing with a large number of animals, which leads to degradation of the vegetation and compaction of the soil.

2.7. Risk Due to Soil Sealing With Inert Materials

Soils are covered with inert materials because of the need to create infrastructures in modern societies for housing and other purposes. The covering of soils with inert materials (soil sealing) results from large-scale residential and industrial development, the associated development of the road network and the development of services such as waste disposal and treatment, water distribution and provision for military requirements (Fig. 5). Unfortunately, this is a constant process in the urban and suburban environment because of the increasing population and its growing demands, resulting in a steady reduction in exposed soils and green zones.

Fig. 5. Soil sealing in the Attic Basin and the wider Attica area with adverse impact on the environment



The breaking of contact between the soil (pedosphere) and the biosphere, hydrosphere and atmosphere affects many natural processes such as the water cycle (percolation, filtration of rainwater, replenishment of underground aquifers and evapotranspiration), energy flows between pedosphere and atmosphere, and the geochemical cycle of elements. In areas of soil which are covered with inert materials, the surfaces engaged in soil functions are limited. The main visible consequence of soil sealing is an increase in surface runoff, which results in an increased flood risk and sometimes flood disasters.

Inevitably, the amount of available soil to meet human needs in modern societies is declining. The preservation of high-yield land which contributes to the production of quality foods, or any other terrain which protects the environment or reduces flood risk, is a question of land-use planning and priorities.

2.8. Risk Due to Desertification of Soils

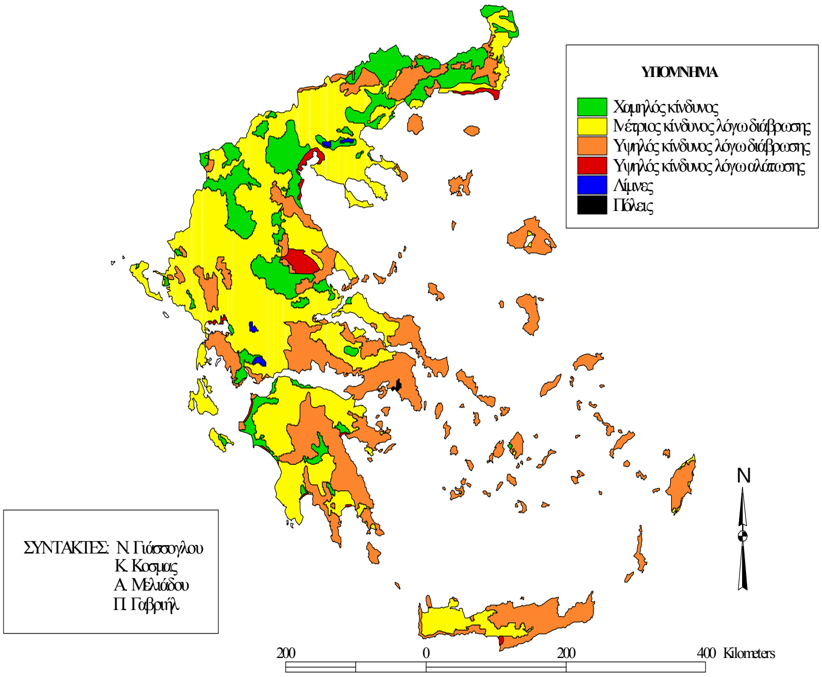
Desertification is a process whereby fertile land is degraded and progressively disappears, leaving patches of denuded land which spread and are likely to merge, forming regions of low productivity. This degradation is thought to be mainly attributable to the activity of humans, who, with their interventions on the environment, often increase the rate of: (a) wind, water and mechanical erosion of soils, (b) degradation of the physical, chemical and biological properties of soil resources, (c) loss of natural vegetation. The primary process responsible for desertification is erosion, which poses the greatest risk of soil degradation on slopes, because it causes a drastic reduction in soil depth, fertility and productivity, and in vegetation. Impending climate change, because of the greenhouse effect, is expected to aggravate the problem, because water shortage is the greatest threat to protection of the Mediterranean environment.

Desertification is a global problem. It is estimated that 170 countries are affected directly by desertification, while another 50 countries are thought to be affected indirectly. According to a study (Dregne et al., 1991) carried out by the International Center for Arid and Semiarid Land Studies in Texas, approximately 70% of the arid regions of the world show signs of desertification. Data presented at the Rio Summit on the Environment in 1992 indicate that more than a third of soils have been affected by desertification, with agricultural land at greatest risk. The rate of cereal production decreased globally from 3% in 1970 to 1.3% in the decade 1983-1993, and one of the factors behind this decrease was poor management of soil and water (Steer, 1998). According to a UN estimate, the loss of agricultural income due to desertification was USD 64 billion in 2006.

The Mediterranean region has suffered significant degradation of its natural resources (Grove, 1996; Thornes, 1996). The phenomenon of desertification is due to a combination of natural factors such as drought, floods and forest fires, and human activities such as intensive exploitation of natural resources, overgrazing, etc. Steadily increasing industrial activity, the spread of tourism and the intensification of agriculture have contributed significantly to the degradation of soils and the desertification of the land in Mediterranean Europe. Specifically, the regions at greatest risk of desertification in southern Europe are the south-east regions of Greece, southern Italy, Sicily, Corsica and the south-east part of the Iberian Peninsula (UNEP, 1992, Imeson and Emmer, 1992).

The territory of Greece shows serious degradation, with many regions at high risk of desertification. The high-risk areas for desertification are a large part of Sterea Ellada, the greater part of the Peloponnese, the mountain zone of the Ionian islands, the Aegean islands, Evvia, eastern Crete, and parts of Thessaly, Macedonia and Thrace. As recent studies by the National Committee for Combating Desertification have shown, 35% of Greek land is at high risk of desertification and 49% at moderate risk (Fig. 6). The remaining 16% of Greek land is considered to be at low risk of desertification.

Fig. 6. Map showing potential desertification risk (National Committee for Combating Desertification)

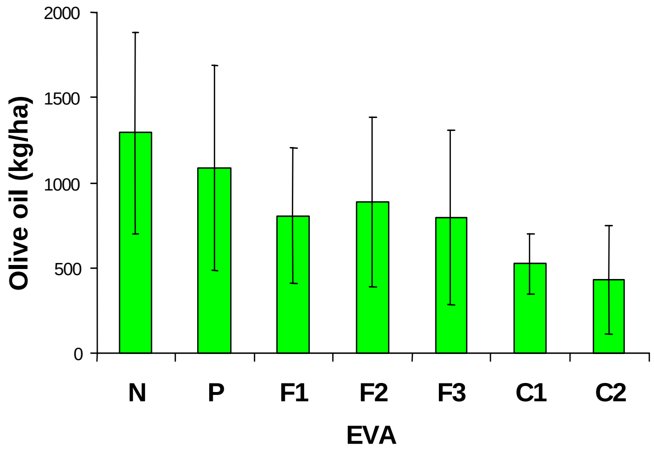


For these reasons, desertification of the land is now one of the main environmental issues at global, national, regional and local level (UNEP, 1992; Imeson, 1996). The new ten-year programme (2008-2018) of the UNCCD (United Nations Convention to Combat Desertification) Secretariat provides for interconnection and collaboration between the three conventions on drought and desertification, climate change, and biodiversity.

Zones vulnerable to desertification are those planted with olives, cereals and vines, and pastureland. Calculations of olive oil production on the island of Lesvos indicate that while average production is 135 kg per 1 000 square metres in areas which are not at risk, it is only a third as much in areas which have become seriously degraded and desertified (Fig. 7).

According to the severity of the factors and processes of desertification, degradation may be a reversible process, i.e. there may be a possibility of recovery if one of the factors or processes is eliminated. Desertification is reversible, for example, where soil moisture has been reduced below the threshold for plant growth but the soil depth is not borderline. Desertification may also be reversible where overgrazing causes a reduction in the biodiversity of an area, with subsequent predominance of plants of low economic value, such as brushwood. Degradation of soils due to salinisation is also reversible. In all these cases, appropriate management interventions can reverse the progress of desertification.

Fig. 7. Variation in average olive oil production with degree of vulnerability to desertification (EVA = area environmentally vulnerable to desertification, N = no-risk area, P = potentially vulnerable, F1, F2, F3 = vulnerable areas, C1, C2 = critical areas for desertification)



On the other hand, irreversible desertification is observed when the ecosystem suffers permanent, irreparable damage. This may be the final stage of an intense process of soil erosion. Permanent desertification is caused when the depth of the root layer is reduced below the limit where plant growth is possible. A direct consequence of this is that the water capacity of the soil is significantly reduced, so that very few plant species can survive.

Desertification, as either a reversible or a permanent process of degradation, is a major environmental problem with dire social and economic consequences. Because of the low productivity of desertified areas, their populations are under-employed or turn to other activities, and often emigrate to areas with better employment opportunities. Given that the gravity of the problem for our country and Mediterranean Europe is self-evident, it is obvious that the protection of our natural resources and ecosystems is an issue of major importance and immediate priority.

Within the scope of implementing the UN Convention to Combat Desertification, Greece drew up a National Action Plan to combat desertification. The Action Plan includes the general anti-desertification measures for various sectors such as livestock rearing, farming, water and soil resources, institutional measures, etc. The adoption of specific protection measures calls for the undertaking of special studies to determine the factors and processes of degradation and desertification of the land, using the methodologies developed under many research programmes funded, in particular, by the EU, such as MEDALUS, DESERTLINKS, DESIRE, MEDRAP, MEDACTION, etc.

3. Conclusions

The specific characteristics of Mediterranean Europe, with its semi-arid climate subject to considerable variation in annual rainfall, its sloping terrain with sharp gradients, long-term use of land, poor and highly eroded soils, extensive forest destruction by fire, abandonment of traditional agriculture, over-exploitation of water resources, and the concentration of economic activity in coastal regions, have caused considerable degradation of agro-ecosystems. As a result of degradation combined with natural disasters such as drought, flooding, forest fires, as well as non-sustainable farming practices, soils often become 'skeletal', saline, arid and infertile. A further risk is soil pollution due to excessive use of fertilisers and pesticides, since it can cause toxicity in plants, a reduction in biodiversity and greater vulnerability to erosion. In addition, the quality of the land and agro-ecosystems may be affected by redistribution of water resources due to construction of reservoirs and canals. The widespread degradation of underground aquifers is an issue of particular concern, especially along coasts where there are increased requirements due to tourism, intensely irrigated farming, and industry. The restoration of a reasonable balance between economic development and protection of agro-ecosystems is a matter of urgency. Some of the protection measures for agro-ecosystems are summarised below:

- minimisation of mechanical tilling of the soil, with a restriction on the use of tractors and on the depth of ploughing;
- preservation of the natural annual vegetation as undergrowth among perennial tree plantations;
- incorporation of plant residues into the soil to increase its organic matter content and reduce greenhouse gas emissions;
- implementation of the subsidised 'set-aside' system as a priority in areas with steep gradients;
- enforcement of a policy to support traditional olive plantations on sloping land;
- implementation of a system for compensating land users for the removal from cultivation of land with a soil depth of less than 30 cm and its transfer to forestry;
- maintenance and preservation of existing berms to protect agro-ecosystems which are vulnerable to degradation;
- demarcation of land uses, taking account of the soil and climatic characteristics and the vulnerability of the land to degradation;
- demarcation of productive land and its strict classification as land exclusively for agricultural use;
- reform of the subsidy system in areas with a serious problem of degradation due, for example, to overgrazing and cereal cultivation;
- implementation of a system of reduced taxation for those land users who apply good practice in the management of natural resources, with corresponding surcharges for land users who do not manage natural resources judiciously;
- enforcement of national and European regulations on the protection of natural resources;
- re-establishment or support of rural development agencies for the transfer of knowledge and technology to land users (farmers) for the sustainable management of natural resources.

Bibliography

- Balesdent et al., 2000. Balesdent, J., Chenu, C. and Balabane, M., Relationship of soil organic matter dynamics to physical protection and tillage, Soil & Tillage Research 53 (2000), pp. 215-230.
- Bryan, R.B. and Campbell, I.A., 1986. Runoff and sediment discharge in a semi-arid drainage basin. Zeit fuer Geomorph, 58, 121-143.
- Dregne, H., Kassas, M. and Rozanov, B., 1991. A new assessment of the world status of desertification. Desertification Control Bulletin 20:6-18, UNEP.
- Epstein, E., 1976. Kinetics of ion transport and the carrier concept. In: Luttage, U., Pittman, M. (eds), Transport in plants. Vol II. Part B. Tissues and Organs. Encyclopedia of Plant Physiology. New Series. Springer Verlag, N.Y.
- El-Swaify, S.A., 1994. State-of-the-art for assessing soil and water conservation needs and technologies. In: Adopting Conservation on the Farm: An International Perspective of the Socioeconomics of Soil and Water Conservation, Soil and Water Conservation Society, Ankeny, pp. 13-27.
- Faulkner, H., 1990. Vegetation cover density variations and infiltration patterns on piped alkali sodic soils: Implications for the modeling of overland flow in semi-arid areas. In: Thornes, J. (ed), Vegetation and erosion, processes and environments. John Wiley & Sons, Chichester, 317-346.
- Gerontidis, S., Kosmas, C., Detsis, B., Marathianou, M., Zafiriou, T., Tsara, M., 2001. The effect of moldboard plow on tillage erosion along a hillslope. Journal of Soil and Water Conservation. Volume 56, Number 2, 147-152.
- Govers, J., Quine, T., Desmet, P., Walling, D., 1996. The relative contribution of soil tillage and overland flow erosion to soil redistribution on agricultural land. Earth Surface Processes and Landforms 21: 929-946.
- Gregorich, E.G., Greer, K.J., Anderson, D.W., Liang, B.C., 1998. Carbon distribution and losses: erosion and deposition effects, Soil & Tillage Research 47 (1998) 291±302.
- Grove, A.T., 1996. The historical context: Before 1850. In: Brandt, J. and Thornes, J. (eds), Mediterranean desertification and land use. J. Wiley & Sons, Chichester, England, 13-28.
- Imeson, A.C., 1996. Desertification research – Thematic issues and spatial and temporal scaling. In: Hill, J., Peter, D. (eds), The use of remote sensing for land degradation and desertification monitoring in the Mediterranean basin. Brussels: European Commission.
- Imeson and Verstraten, 1989. Imeson, A. and Verstraten, J.M., The microaggregation and erodibility of some semi-arid and Mediterranean soils. Catena Suppl. 14 (1989), pp. 11-24.
- Imeson, A. C. and Emmer, I. M., Implications of climate change on land degradation in the Mediterranean. In Climate Change and the Mediterranean. 95-128. L. Jeftic et al, (Eds.). London (UK): Edward Arnold. 1992.
- Karczewski, T., 1978. Wpływ prędkości przejazdu na zmiany zagęszczenia gleby przez koła maszyn rolniczych. Z. Probl. Post. Nauk Roln., 201: 69-74 (in Polish).

- Konstankiewicz, K., 1977. The influence of pore distribution on water potential in soils subjected to consolidation. Z. Probl. Post. Nauk Roln., 197: 79-97.
- Kosmas, C., Moustakas, N., Danalatos, N. and Yassoglou, N., 1996. The Spata Field Site: I. The Impacts of Land Use and Management on Soil Properties and Erosion. II. The Effect of Reduced Moisture on Soil Properties and Wheat Production. In: J. Brandt, and J. Thornes [eds], Mediterranean Desertification and Land Use. John Wiley & Sons, Chichester.
- Kosmas, C., Gerontidis, St., Marathianou, M., Detsis, V., and Zafiriou, Th. 2001. The effect of tillage erosion on soil properties and cereal biomass production. Soil & Tillage Research J. 58:31-44.
- Lal, R. 1995. Global soil erosion by water and carbon dynamics. In Soils and global change, eds. R. Lal, J. Kimble, E. Levine and B.A. Stewart, 131-142. Boca Raton, Fla.: CRC/Lewis Publishers.
- Lawrence, G.P., 1978. Stability of soil pores during mercury intrusion porosimetry. J. Soil Sci., 29: 299-304.
- Lobb, D., Kachanoski, R., Miller, M., 1995. Tillage translocation and tillage erosion on shoulder slope landscape positions measured using 137Cs as a tracer. Canadian Journal of Soil Science, 75, 211-218.
- Mitchell, D., 1990. The use of vegetation and land use parameters in modeling catchment sediment yields. In: Thornes, J. (ed), Vegetation and erosion, processes and environments. Wiley, Chichester, 289-314.
- Quine, T., Desmet, P., Vandaele, K., Govers, G., Walling, D., 1994. A comparison of the roles of tillage and water erosion in landform development and sediment export on agricultural land near Leuven, Belgium. In: Variability in stream erosion and sediment transport. Proceedings of the Camberra Symposium, December, 1994. IAHS Publication No. 224, 77-86.
- Quine, T., Govers, G., Walling, D., Zhang, X., Desmet, J., Zhang, Y., Vandaele, K., 1997. Erosion processes and landform evolution on agricultural land – new perspectives from Caesium-137 measurements and topographic-based erosion modeling. Earth Surface Processes and Landforms 22: 799-816.
- Rengasamy, P., 1998. Sodic soils. In: Lal, R., Blum, W., Valentine, C., Stewart, B. (eds), Methods for assessment of soil degradation. CRC Press. pp. 265-277.
- Smith, R., Stamey, W., 1965. Determining the range of tolerable erosion. Soil Science 100, 414-424.
- Steer, A., 1998. Making development sustainable. Adv. In Geo-Ecology 31:857-865.
- Szabolks, I., 1989. Salt affected soils. CRC Press, Boca Raton, Florida.
- Thornes, J., 1996. Desertification in the Mediterranean. In: Brandt, J. and Thornes, J. (eds), Mediterranean desertification and land use. J. Wiley & Sons, Chichester, England, 1-12.
- Tsara, M., Gerontidis, S., Marathianou, M., Kosmas, C., 2001. The long-term effect of tillage on soil displacement of hilly areas used for growing wheat in Greece. Soil Use and Management, 17, 113-120.
- UNEP, 1992. World Atlas of Desertification. United Nations Environment Programme. London: Edward Arnold.

4. Research and development on soil protection Vale do Gaio Portugal – a case study

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CONTENTS

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Executive Summary

This document reports the results of applying, in the Vale do Gaio basin in the Alentejo region, Portugal, of the indicators 'estimated soil loss by water erosion' and 'area at risk of desertification' selected by the Environmental Assessment of Soil for Monitoring (ENVASSO) Project http://www.envasso.com/) to assess the threats to soil identified in the 'Soil Communication' COM (2002) 179.

The ENVASSO Project's main objective was to select and test criteria and indicators for quantifying the threats to soil identified in the 'Soil Communication' COM (2002) 179, namely erosion, desertification, decline in organic matter, contamination, compaction, sealing, decline in biodiversity, salinisation and landslides. The criteria and indicators produced by the project establish minimum and maximum admissible levels, which were tested in pilot areas (e.g. Vale do Gaio) in the countries in which the necessary data were available.

The Vale do Gaio basin, with an area of approximately 513 km^2, forms part of the Sado basin. The dominant soils are cambisols, luvisols and regosols, characterised by low levels of organic matter and low rates of infiltration and water retention. Cork and oak plantations and dry farming systems are the main forms of land use. Tillage practices, which generally coincide with the beginning of the rains, and water erosion of the soil are the main causes of soil degradation in the pilot area. Soil erosion rates due to water erosion were estimated using the PESERA model, in accordance with ENVASSO project guidelines. Areas at risk of desertification were classified using the methodology developed by the MEDALUS project.

The ENVASSO project defined eight types of soil loss. When the rate of erosion is less than 0.5 tonnes/ha/year, there is no risk of erosion. Rates higher than 2 tonnes/ha/year must be corrected. Erosion rates in the Vale do Gaio were calculated for the period 2001-2006, using the PESERA model. It was found that erosion rates were less than 0.5 tonnes/ha/year in 32% of the basin and higher than 2 tonnes/ha/year in 60% of the area. The land that presents no risk of water erosion is mainly located in the west and southeast in areas with cork and oak plantations. Although the plantation system may be associated with extensive agriculture and pasture under the tree canopy, it provides a lot of protection against soil erosion, even where there are steep slopes, because the soil is covered by vegetation for most of the year. The land most at risk from erosion is in the centre and northeast, in areas of more intensive agriculture, both dry and irrigated. Tillage in preparation for planting of winter crops, which generally coincides with the beginning of the rains, increases the loss of soil due to water erosion and helps to explain the greater estimated soil loss in these areas.

The risk of desertification in the Vale do Gaio basin was analysed for the same period, using the MEDALUS methodology, with 68% of the area classified as fragile and 26% as critical. Only 4% was classified as potentially affected and 2% as non-affected. These results show a more critical situation than those obtained by analysing the risk of erosion, showing that this is the main cause of desertification, but not the only one.

Introduction

Agricultural soils in the European Union are being degraded. The process is more acute in the countries of southern Europe because of climatic reasons. Degradation due to soil sealing, associated with urban growth, and compaction, associated with the use of heavy agricultural machinery, is common to all countries. Erosion, the decline in organic matter and salinisation are more serious in the Mediterranean region and cause desertification, which is defined as land degradation in arid, semi-arid and dry sub-humid areas resulting from various factors, including climatic variations and human activities, leading to the loss of one or more functions of the soil (UNCCD, Article 1). Arid, semi-arid and dry sub-humid areas are areas, other than polar and sub-polar regions, in which the ratio of annual precipitation to potential evapotranspiration (P/ET0) falls within the range of 0.05 to 0.65 (Rubio and Recatala).

Scientific research into soil protection (and consequently into combating desertification) looks at the processes of soil degradation. These processes may be analysed separately but are often studied together because of their interdependence. For example, a loss in organic matter reduces the water retention capacity and fertility of soil, reducing vegetation and increasing erosion and the need for irrigation, which may increase the risk of salinisation.

Susceptibility to desertification is the most important criterion when deciding on priorities for research into soil degradation.

Susceptibility to desertification

Desertification indicators are an expeditious way of assessing the link between desertification and (i) soil properties, (ii) climate properties, (iii) vegetation cover and (iv) land use. The MEDALUS project (Kosmas et al.), funded by the European Union, used these parameters to propose a susceptibility to desertification indicator that distinguishes between: critical areas, fragile areas, areas potentially affected and areas not affected by desertification.

Desertification may be identified by the level of soil degradation. The indicator proposed by the MEDALUS project assesses the risk, but does not quantify the process.

Causes of desertification

Forty scientific institutions from various member countries of the European Union participated in the ENVASSO Project (http://www.envasso.com/), which was funded by the Sixth Framework Programme for the period 2006-2007. One of the project's main objectives was to define quantitative indicators for each threat to the soil identified in the Communication 'Towards a Thematic Strategy on Soil Protection' (COM (2002) 179), namely erosion, decline in organic matter, contamination, sealing, salinisation, compaction, decline in biodiversity and landslides and confirmed by the Communication 'Thematic Strategy for Soil Protection' COM (2006) 231, which emphasised the importance of desertification as a process of soil degradation that is expected to intensify in the event of climate change.

The proposed indicators were tested in a series of pilot areas in Europe and recommendations were made for the harmonisation of soil monitoring activities. Mathematical modelling was also identified as an essential tool for quantifying risks and developing soil protection strategies.

The proposals and recommendations made by the project were accepted by the 40 participating teams and provide a basis for implementing harmonised and comparable research and development into soil protection.

In order to characterise desertification, the ENVASSO Project adopted an indicator proposed by the MEDALUS project: 'environmentally sensitive area to desertification' (km2 or %).

The main threats in southern Europe

The main causes of soil degradation in southern Europe are erosion, decline in organic matter and salinisation.

Erosion

Soil erosion is a natural process, but becomes a threat when it proceeds more rapidly than the rate of soil formation and when it is accelerated by human activity.

Various studies indicate average rates of soil erosion in Europe at between 10 and 20 tonnes/ha/year. However, Huber et al. defined tolerable soil loss as only 1 to 2 tonnes/ha/year. Measurement of the rate of soil erosion is always restricted to a limited number of locations where the risk is moderate or high and that are representative of agroecological zones. Soil erosion rates vary greatly in time and space, which makes it difficult to apply the results to larger areas or extrapolate them to areas where measurements have not been carried out. Soil erosion can also be estimated using other tools, including erosion models. The most commonly used are based on the Universal Soil Loss Equation (USLE) (Wischmeier and Smith) and the Revised Universal Soil Loss Equation (RUSLE) (Renard et al.). More recently, Kirkby et al. (2004) designed a Pan-European Soil Erosion Risk Assessment (PESERA) model, which estimates the loss of sediment, with reference to water erosion. Although it is considered that these tools provide acceptable estimates of soil erosion, there are few locations in Europe where soil erosion has been systematically measured over a sufficient period of time to provide data that allow models to be effectively calibrated and validated. The distribution of soil monitoring locations in arid, semi-arid and dry sub-humid zones, as identified by the ENVASSO Project, appears to be insufficient to provide a complete picture of existing soil types and land use. A further 800 locations would be needed to achieve the soil monitoring density present in the rest of Europe (Kibblewhite et al.).

Within the framework of the ENVASSO Project, Huber et al. selected the PESERA model as one of the most appropriate methods to quantify the 'soil loss due to water erosion' indicator because, unlike other methods, it made it possible to compare results from the different regions of Europe. The PESERA model uses climate, vegetation, soil and topographic data. The accuracy of results increases in accordance with the resolution of the information used.

The PESERA model was used in pilot areas in European countries where the data required to specify the parameters and validate the results were available. The exercise showed that data are very scarce and that different methodologies are used to obtain baseline data, making it difficult to compare results from different countries.

Decline in organic matter

The loss of organic matter is closely associated with soil microorganisms, which become more active as the temperature increases. It is therefore potentially higher in Mediterranean countries, where agricultural practices should take account of this risk. The loss of organic matter reduces the soil's productivity and capacity to retain water. A reduction in vegetation also increases the risk of erosion. The loss in organic matter is therefore one of the main causes of desertification in the countries of southern Europe. Minimising the decline in organic matter is achieved by appropriate (i) land use (ii) soil tillage practices, (ii) careful choice of agricultural (cereals, orchards, pasture) and forest crops and (iii) vegetation cover. All these aspects directly affect the production and/or degradation of organic matter and may also have an impact on erosion and the infiltration of water when it rains.

The ‘topsoil organic carbon content’ was chosen as an indicator of the decline in organic matter, with the guideline that it should be measured every 10 years.

Salinisation

Salinisation of the soil increases the salt content of the soil and the water in the soil (soil solution) and reduces agricultural productivity. Salinisation increases in accordance with the intensity of irrigation and the reduction in water quality (measured as salt content) and is therefore especially serious in southern Europe.

The ENVASSO Project established ‘salt profile’ as an indicator, represented by the total salt content in each layer, as measured by the electrical conductivity of samples of saturated soil.

The effect of irrigated water quality depends on soil properties, but also on the rainfall regime itself. The first determines the soil's capacity to retain salts, while rainfall is the vehicle for their removal. A combination of field tests and mathematical model studies involving the dynamics of water and the transport of solutions is essential (Gonçalves et al.).

1. Methodologies for Soil Erosion and Desertification Risk Assessment. Case Study: Vale do Gaio Basin

The objective of the Vale do Gaio basin (Alentejo, Portugal) case study was to test the erosion and desertification risk criteria and indicators defined by Huber et al. for the ENVASSO Project. The risk of soil loss through water erosion was assessed using the PESERA model (Kirkby et al. 2004, 2008). The areas at risk of desertification were assessed using the MEDALUS methodology (Kosmas et al.).

The PESERA Model

The PESERA (Pan-European Soil Erosion Risk Assessment) model developed by Kirkby et al. (2004; 2008), makes it possible to estimate soil loss due to water erosion (tonnes/ha/year), although the detail of the estimates depends on the resolution of the data used. The model is based on a conservative erosion model, which is broken down into components of climate, vegetation and soil use, soil properties and topography. The rate of sediment transport (proportional to the sum of the square of water erosion) is estimated as a mean soil loss (tonnes/ha), obtained as a product of the model components. As the components are explicit, the impact of changes in land use or climate can be identified in such a way that the susceptibility to changes can be explored.

Table 1 presents the minimum information necessary for the PESERA model.

Table 1. Data required for the PESERA model (Irvine & Kosmas, 2003).

Data	Description	No of Layers
Vegetation	Root depth (mm).	1
	Initial surface storage of water by the soil due to its roughness (mm).	1
	Reduction in surface storage of water after one month (%).	1
	Land use (-).	1
	Coverage in each month (%).	12
Climate	Monthly mean rainfall (mm).	12
	Monthly mean temperature (ºC).	12
	Monthly temperature range (ºC).	12
	Monthly coefficient of variation of rain per rain day (-).	12
	Mean rain per rain day (mm).	12
	Monthly mean potential evapotranspiration (mm).	12
Soil	Soil storage (mm).	1
	Crusting (mm).	1
	Erodibility (mm).	1
	Soil depth (mm).	1
Topography	Standard deviation of elevation (m).	1

The MEDALUS Methodology

The MEDALUS (Mediterranean Desertification and Land Use) methodology, developed by Kosmas et al., allows estimates to be made of environmentally sensitive areas (ESAs) to desertification using a multi-factor analysis of soil quality indices (SQI), climate quality indices (CQI), vegetation quality indices (VQI) and land use quality indices (MQI). These indices are calculated in the following way:

SQI = (texture × parent material × rock fragments × soil depth × slope gradient × drainage)$^{1/6}$ (1)

CQI = (precipitation × aridity × aspect)$^{1/3}$ (2)

VQI = (fire risk **×** soil erosion protection × drought resistance × plant cover)$^{1/4}$ (3)

MQI = (land use intensity × protection policies)$^{1/2}$ (4)

The parameters for each quality index are assigned a weight according to their soil protection capacity. The weight of each index can be found in Kosmas et al.

The following equation is used to calculate the environmentally sensitive areas (ESAs) to desertification:

ESAI = (SQI × CQI × VQI × MQI)1/4 (5)

ESAs are classified as critical (C3, C2 and C1), fragile (F3, F2 and F1), potentially affected (P) and non-affected (N) desertification zones. Classification is to some extent subjective. Critical areas (C3, C2 and C1) are already very degraded due to past misuse, presenting a threat to the environment of surrounding areas. Fragile areas (F3, F2 and F1) are where any change in the delicate balance of natural and human activity is likely to bring about desertification of the ecosystem. Potentially affected areas (P) are at risk of desertification in the event of significant climate change, if a particular combination of land use is implemented or where offsite impacts will cause serious problems. This also includes abandoned land that has not been properly managed. Non-affected areas (N) are areas with deep to very deep, nearly flat, well-drained, coarse-textured or finer soils under semi-arid or wetter climatic conditions, irrespective of vegetation.

The Vale do Gaio Basin

The Vale do Gaio basin (Figure 1) has an area of 513 km2 and is located in the Alentejo region, in the Sado basin. The relief is gently undulating, typical of the Alentejo plateau, with slopes of less than 6% in 96% of the area. The elevation is between 39 and 418 m. The elevation, gradient and exposure of the slopes in the basin were determined using a digital model of the terrain, on a 250 × 250 m grid.

Figure 1. Location of the Vale do Gaio basin.

The main soil groups in the Vale do Gaio basin are cambisols and luvisols (FAO). There are also regosols, fluvisols, vertisols and leptosols, but in lesser quantities. Given that the Cartas de Solos 1:25000 (Soil Maps) only describe cartographic units and do not have associated analytical databases, the soils were inevitably classified using existing information on representative profiles of these soils (Serviço de Reconhecimento e de Ordenamento Agrário; Ramos et al.), in order to satisfy the requirements necessary to apply the methodologies of Kirkby et al. (2004) and Kosmas et al.. On the basis of this information: (i) the soils are shallow (15-30 cm) in 13% of the area, of moderate depth (30-75 cm) in 48% of the area and deep in 36%; (ii) the surface texture is coarse in 79% of the area; (iii) the usable water capacity is low (<50 mm) in 10% of the area, medium (50-100 mm) in 39% of the area, high (100-150 mm) in 37% of the area and very high (>150 mm) in 14% of the area; (iv) the luvisols have drainage problems, as shown by the information on badly-drained areas in the Cartas de Solos 1:25000; (v) stoniness was also determined using information on stoniness and rock outcrops provided by the Cartas de Solos 1:25000.

The parent material was determined using the Geological Map (1:50000) of the Portuguese Geological Services. The main material is granite, accompanied by schists, arenites and unconsolidated materials.

Land use was defined using the Corine Land Cover Map 2001. Plantation and dry farming systems are dominant. The plantation system, composed of cork (Quercus suber) and oak (Quercus rotundifolia) trees, covers around 34% of the basin, mainly in the west and southeast. Dry farming systems, which are sometimes associated with the plantation system, cover around 48% of the basin, mainly in the central areas and northeast. The urban areas of Évora and Viana do Alentejo are also in the basin. There are also a few irrigated areas.

The small size of the basin meant that only the meteorological data provided by the Vale do Gaio meteorological station (38.25 ºN; -8.29 ºW, WGS84) of the network administered by the National Water Institute were used. The climate can be classified as Csa (Köppen) or C2B'2s2a' (Thornthwaite). The daily and monthly precipitation and mean monthly temperature figures refer to the period 1979-2006. Given the scarcity of data, the monthly evapotranspiration reference was calculated for the period 2001-2006. The Bagnouls-Gaussen aridity index for the region is 132. The meteorological information required by the PESERA and MEDALUS models is presented in Table 2.

Table 2. The meteorological information required by the PESERA and MEDALUS models obtained from the Vale do Gaio meteorological station (38.25 ºN; -8.29 ºW, WGS84)

Month	Precipitation (mm)	r0 (mm)	C.V. r0	Mean T. (ºC)	T Range (ºC)	ET_0 (mm)
January	64.7	5.4	1.28	9.1	11.4	20.9
February	58.1	5.7	1.08	10.2	11.0	35.4
March	36.7	4.7	1.22	12.7	11.7	63.3
April	54.8	5.0	1.23	14.3	12.6	94.2
May	39.5	4.9	1.02	17.7	13.5	127.4
June	11.3	4.3	1.06	21.2	15.2	151.9
July	5.3	3.6	0.71	23.8	15.9	169.2
August	4.0	2.7	0.83	23.3	16.1	147.9
September	26.5	4.9	1.20	21.2	14.6	100.7
October	73.1	6.3	1.25	17.3	10.6	60.6
November	86.9	6.8	1.47	13.2	10.4	28.7
December	87.5	5.7	1.25	10.4	10.1	18.8
Annual	548.4	5.0	1.1	16.2	12.8	1019.0

r0 – Mean precipitation per number of rain days (1979-2006); C.V. r0 – Coefficient of variation of r0; Mean T. – Monthly mean temperature (1979-2006); T Range – Temperature range (1979-2006); ET_0 – Evapotranspiration reference (2001-2006)

2. Results and Discussion

Estimated Soil Loss Due to Water Erosion

The estimated risk of soil loss due to water erosion in the Vale do Gaio basin is presented in Figure 2. The percentage of the area in each class of risk of water erosion is set out in Table 3. According to the PESERA model, 32.1% of the area is at risk of water erosion of <0.5 tonnes/ha/year. These areas are mainly in the west and southeast, where land use includes cork and oak plantations, despite the fact that some of these areas have relatively steep slopes. Although the plantation system may be associated with extensive agriculture and pasture under the tree canopy, it provides a lot of protection against soil erosion, because the soil is covered with vegetation for most of the year. The land most at risk from erosion is in the centre and northeast, in areas of more intensive agriculture, both dry and irrigated. The areas at most risk of water erosion were those that presented losses of between 5-10 and 10-20 tonnes/ha/year, corresponding to 23.3% and 16.9% of the area respectively. Tillage in preparation for planting of winter crops, which generally coincides with the beginning of the rains, results in a greater quantity of soil being lost due to water erosion and helps to explain the greater estimated soil loss in these areas using the PESERA model. It was also found that the risk of water erosion in 60% of the Vale do Gaio basin was greater than 2 tonnes/ha/year, a figure defined by Huber et al. as the tolerable limit for soil erosion.

Figure 2. Estimate of soil erosion in the Vale do Gaio basin using the PESERA model.

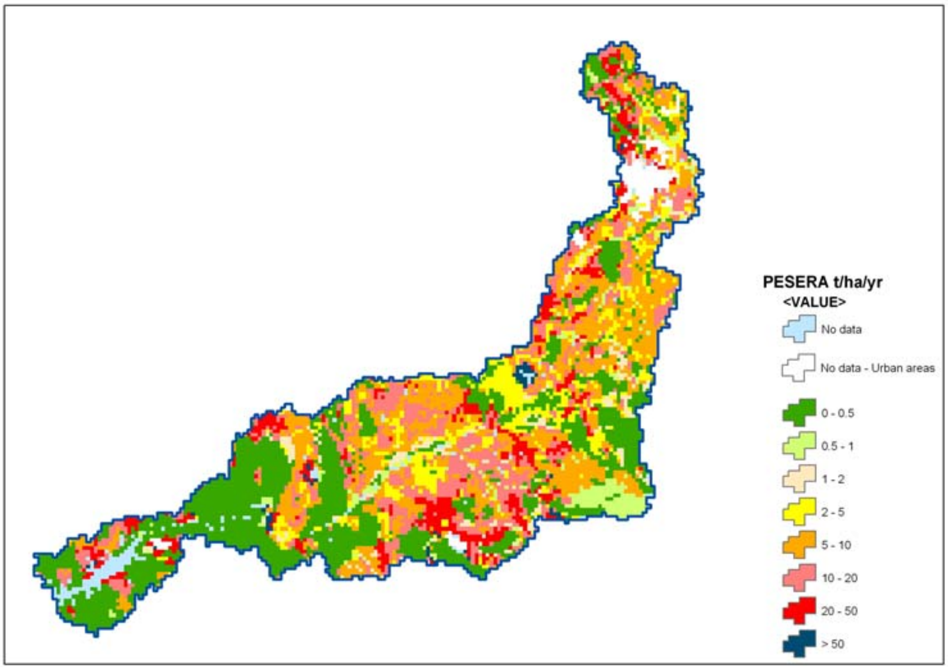

Table 3. Soil loss in the Vale do Gaio basin using the PESERA model.

Rate of erosion (tonnes/ha/year)	< 0.5	0.5-1	1-2	2-5	5-10	10-20	20-50	>50
Area (%)	32.1	4.2	3.4	10.2	23.3	16.9	9.0	0.8

Areas Environmentally Sensitive to Desertification

Figure 3 shows the soil quality (SQI) and climate quality (CQI) indices and Figure 4 shows the vegetation quality (VQI) and land use quality (MQI) indices. According to the MEDALUS methodology, the SQI indicates soils of moderate and good quality in 82.4 and 16.7% of the area respectively. The CQI considers 74% of the area to have a moderate climate and a poor climate on slopes with a southern exposure (25.9%). The vegetation is classified (VQI) as being of good quality in 89% of the area, because the plants, including the cork and oak trees, which are resistant to drought and fire, are dispersed in the landscape and provide a high degree of protection against soil erosion. The vegetation was classified as of moderate quality in the rest of the area. With regard to land use (MQI), 81.4% of the basin is of moderate quality, with 18.6% considered to be low quality, because of the gradients in these locations.

Figure 3. Soil quality index (SQI) and climate quality index (CQI).

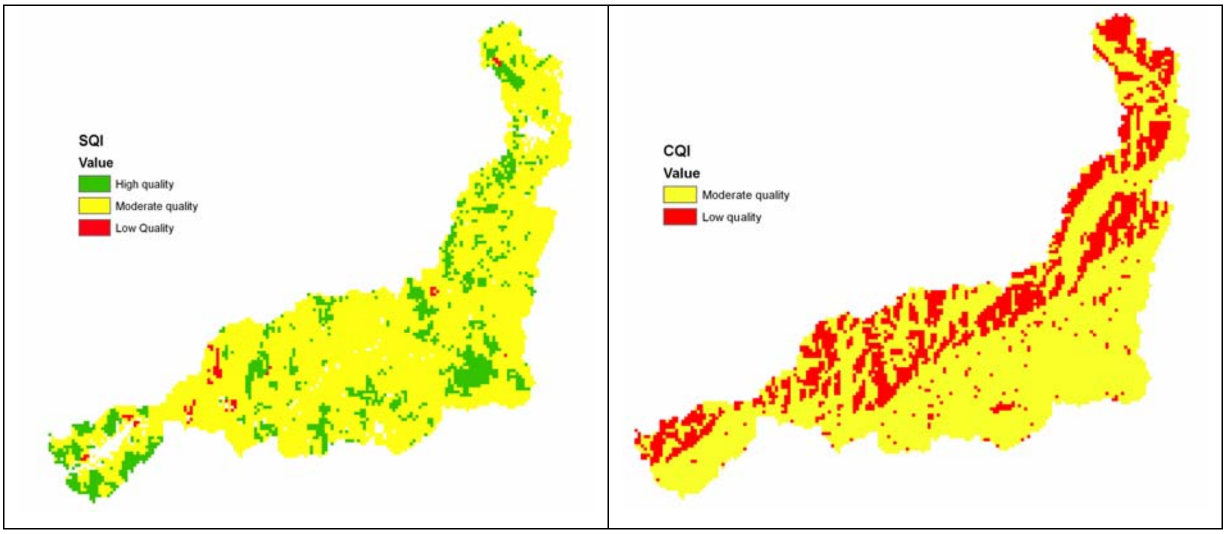

Figure 4. Vegetation quality index (VQI) and land use quality index (MQI).

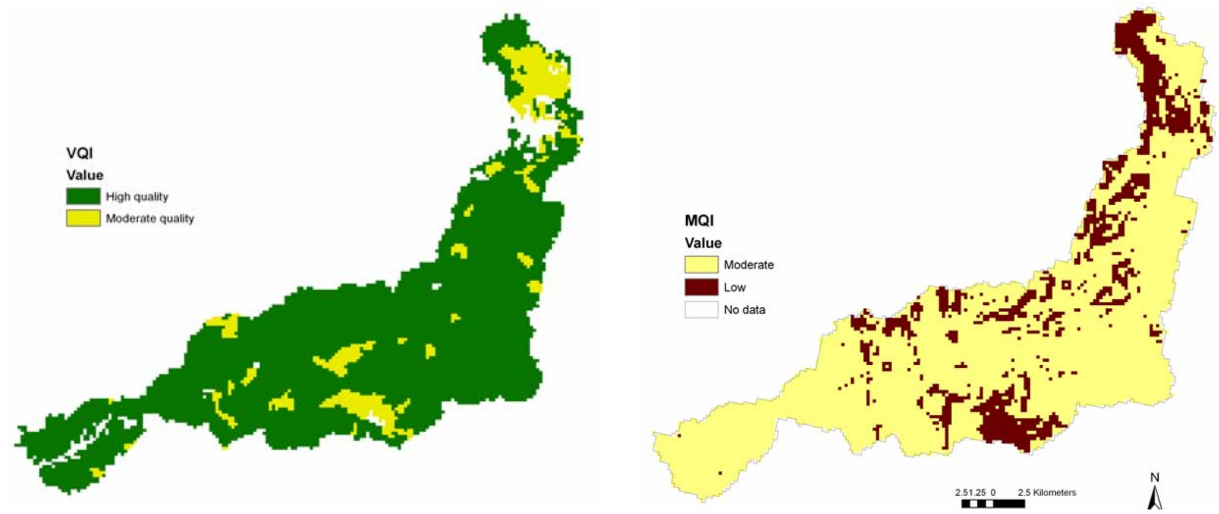

Figure 5 shows environmentally sensitive areas to desertification, in accordance with the MEDALUS methodology.

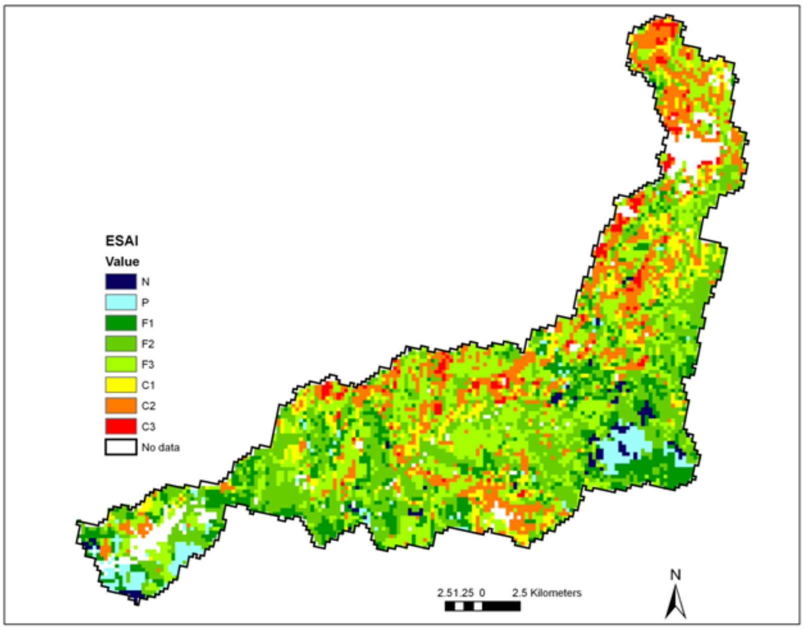

Figure 5. Environmentally sensitive areas to desertification in the Vale do Gaio basin.

Table 4 presents the percentages corresponding to each of these areas. Approximately 26% of the basin is classed as Critical (C1, C2 and C3). These areas are located mainly on south-facing slopes but also in southern and northeastern areas with more intensive land use. An improvement in agricultural techniques could reduce the risk of desertification in some of these areas. Most of the Vale do Gaio basin (68%) is classed as Fragile (F1, F2 and F3). The F1 category is more prevalent in the west and southeast of the basin, where the plantation system predominates. The F3 category, which is closer to the critical category, is more prevalent in the centre and northeast, in areas where agriculture is more intensive. The fragile areas are very sensitive to the type of land use, climate and vegetation. Any changes caused by the loss of vegetation due to fires, for example, or long periods of drought or an increase in soil erosion may cause desertification and require reclassification of Fragile zones into Critical zones.

Table 4. Environmentally sensitive areas to desertification (ESAs) (%).

Class	Non affected	Potential	Fragile			Critical		
	N	P	F1	F2	F3	C1	C2	C3
Area (%)	1.8	3.9	17.1	24.8	26.5	10.4	13.1	2.4

Critical areas in the Vale do Gaio basin (26%) were less widespread than those obtained by Roxo et al. for Mértola municipality (36%). On the other hand, fragile areas were more widespread in the Vale do Gaio basin (68%) in comparison to Mértola municipality (47%).

3. Conclusions

Soil is subject to pressures that may lead to the loss of some of its functions and consequently to desertification. If the risk of desertification is to be identified, information is required about the characteristics of the soil, climate, vegetation and land use. Comparison of the situation in different countries requires comparison of methodologies and harmonisation of data, as has been done with the implementation, for example, of the Water Framework Directive.

Research projects supporting soil protection activities must include the development of databases on a European scale and the harmonised use of models, in order to be able to compare situations in each country and maximise the production of soil management tools. The PESERA model, used to estimate the risk of soil erosion due to water erosion and the MEDALUS methodology, used to assess the risk of desertification in the Vale do Gaio basin, within the framework of the ENVASSO project, provided consistent results with the areas at greatest risk of erosion corresponding to the areas at greatest risk of desertification.

We found that 60% of the Vale do Gaio basin shows an estimated soil loss greater than 2 tonnes/ha/year, the level defined by the ENVASSO Project as the maximum tolerable for soil erosion. With regard to the classification of environmentally sensitive areas to desertification, 26% of the area is classed as critical, that is, it is already very degraded due to past misuse, while 68% is classed as fragile, that is, where any change in the delicate balance of natural and human activity is likely to bring about desertification of the ecosystem. Although the plantation system may be associated with extensive agriculture and pasture under the tree canopy, it provides a lot of protection against soil erosion, even where there are steep slopes, because the soil is covered by vegetation for most of the year.

Application of the PESERA model and the MEDALUS methodology often require simplified hypotheses to compensate for the lack of field data. However, these models have the advantage of easily allowing comparison of results between different regions and countries. Systematic soil erosion monitoring campaigns in Europe, especially in the south, will reduce the uncertainty associated with the application of these methodologies and extend their use to other aspects of soil conservation relevant to the fight against desertification.

Approval of the Soil Framework Directive, as with the Air and Water Framework Directives, is essential for the implementation of monitoring programmes and the creation of research programmes on the sustainable use of soil, with the effective participation of users and local communities. The results of these programmes will give support to public awareness-raising and education initiatives that aim to promote understanding of the causes and effects of the degradation of land and consequent desertification and promote their prevention.

Bibliography

- FAO, World reference base for soil resources. A framework for international classification, correlation and communication. *World Soil Resources Reports* 103. Food and Agriculture Organization of the United Nations, Rome, 2006, 128pp.
- Gonçalves, M. C., Šimůnek, J., Ramos, T. B., Martins, J. C., Neves, M. J. and Pires, F. P., Multicomponent solute transport in soil lysimeters irrigated with waters of different quality, *Water Resour. Res.*, 42, W08401, doi:10.1029/2005WR004802, 2006, 17pp.
- Huber, S., Prokop, G., Arrouays, D., Banko, G., Bispo, A., Jones, R., Kibblewhite, M., Lexer, W., Möller, A., Rickson, J., Shishkov, T., Stephens, M., Van den Akker, J., Varallyay, G. and Verheijen, F., *Indicators and Criteria report*. ENVASSO Project (Contract 022713). Coordinated by Cranfield University, UK, for Scientific Support to Policy, European Commission 6th Framework Research Programme, 2007, 354pp.
- Irvine, B. and Kosmas, C., PESERA *User's Manual. PESERA* Technical Report Deliverable 15, European Commission funded fifth framework project - contract QLK5-CT- 1999-01323, 2003, 34pp.
- Kibblewhite, M., Rubio, J. L., Kosmas, C., Jones, R., Arrouays, D., Huber, S. and Verheijen, F. *Environmental Assessment of Soil for Monitoring Desertification in Europe*. Eighth session of the Conference of the Parties (COP 8) to the United Nations Convention to Combat Desertification (UNCCD), Madrid, Spain, 2007, 62pp.
- Kirkby, M.J., Jones, R.J.A., Irvine, B., Gobin, A, Govers, G., Cerdan, O., Van Rompaey, A.J.J., Le Bissonnais, Y., Daroussin, J., King, D., Montanarella, L., Grimm, M., Vieillefont, V., Puigdefabregas, J., Boer, M., Kosmas, C., Yassoglou, N., Tsara, M., Mantel, S., Van Lynden, G.J. and Huting, J., Pan-European Soil Erosion Risk Assessment: The PESERA Map, Version 1 October 2003. Explanation of Special Publication Ispra 2004 No.73 (S.P.I.04.73). *European Soil Bureau Research Report* 16, EUR 21176, Office for Official Publications of the European Communities, Luxembourg, 2004, 18pp. and 1 map in ISO B1 format.
- Kirkby, M. J., Irvine, B., Jones, R. J. A. and Govers, G., The PESERA coarse scale erosion model for Europe. I – Model rationale and implementation. *European Journal of Soil Science*, 59 (6), 2008, pp. 1293-1306.
- Kosmas, C., Kirkby, M. and Geeson, N., *The MEDALUS Project: Mediterranean desertification and land use.* Manual of Key indicators and mapping environmentally sensitive areas to desertification. EUR 18882 EN. Office for Official Publications of the European Communities, Luxembourg, 1999, 88pp.
- Ramos, T. B., Gonçalves, M. C., Martins, J. C. and Pires, F. P., *PROPSOLO – Base de dados georreferenciada de propriedades do solo*. II Congresso Nacional de Rega e Drenagem, CD-ROM, Fundão, 2007, 13pp.
- Roxo, M. J., Mourão, J. M., Rodrigues, L. and Casimiro, P. C., Application of the proposed methodology for defining ESAs: 3. The Alentejo region (Mértola municipality, Portugal). *In*: C. Kosmas, M. Kirkby and N. Geeson (eds.). *The MEDALUS Project: Mediterranean desertification and land use*. Manual of Key indicators and mapping environmentally sensitive areas to desertification. EUR 18882 EN. Office for Official Publications of the European Communities, Luxembourg, 1999, pp. 80-84.

- Renard, K. G., Foster, G. R., Weessies, G. A., McCool, D. K. and Yoder, D. C., Predicting Soil Water erosion: A guide to conservation planning with the Revised Universal Soil Loss Equation (RUSLE). U.S. Department of Agriculture, *Agriculture Handbook* 703, 1997, 100pp.
- Serviço de Reconhecimento e de Ordenamento Agrário, Carta de solos de Portugal. Classificação e caracterização dos solos de Portugal. II Volume. Dados analíticos das unidades pedológicas. *Boletim de solos* 16. Secretaria de Estado da Agricultura, Ministério da Agricultura, 1973, 252pp.
- Rubio, J. L. and Recatala, L. The relevance and consequences of Mediterranean desertification including security aspects. *In*: W.G. Kepner, J.L. Rubio, D. Mouat and F. Pedrazzini (eds), *Proceedings of the NATO Mediterranean Workshop. Desertification in the Mediterranean Region: A security Issue*, Valencia, Spain, 2005, pp. 133–165.
- Wischmeier, W. H. and Smith, D. D., Predicting rainfall erosion losses. A guide to conservation planning. US Department of Agriculture, Agriculture Handbook 537. 1978, 58pp.

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