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The State of Soil in Europe

A contribution of the JRC to the European Environment Agency's Environment State and Outlook Report— SOER 2010

Arwyn Jones, Panos Panagos, Sara Barcelo, Faycal Bouraoui, Claudio Bosco, Olivier Dewitte, Ciro Gardi, Markus Erhard, Javier Hervás, Roland Hiederer, Simon Jeffery, Anke Lükewille, Luca Marmo, Luca Montanarella, Claudia Olazábal, Jan-Erik Petersen, Vit Penizek, Thomas Strassburger, Gergely Tóth, Miet Van Den Eeckhaut, Marc Van Liedekerke, Frank Verheijen, Eva Viestova, Yusuf Yigini

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The State of Soil in Europe

A contribution of the JRC to the EEA Environment State and Outlook Report — SOER 2010

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"All natural resources ... are soil or derivatives of soil. Farms, ranges, crops, and livestock, forests, irrigation water and even water power resolve themselves into questions of soil. Soil is therefore the basic natural resource." -- Aldo Leopold (1924) "Erosion and Prosperity"

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EXECUTIVE SUMMARY

Nearly all of the food, fuel and fibres used by humans are produced on soil. Soil is also essential for water and ecosystem health. It is second only to the oceans as a global carbon sink, with an important role in the potential slowing of climate change. Soil functions depend on a multitude of soil organisms which makes it an important part of our biodiversity.

Nevertheless, soil resources in many parts of Europe are being over exploited, degraded and irreversibly lost due to inappropriate land management practices, industrial activities and land use change that lead to soil sealing, contamination, erosion and loss of organic carbon.

This Reference Report presents a pan-European perspective on the state soil in Europe in light of available data held within the European Soil Data Centre (ESDAC) and the research activities within the JRC. Managed on behalf of EU institutions by the JRC, the ESDAC operates as a focal point for pan-European data and information on soil.

The core of this report was prepared for the Assessment of Soil[1] that formed part of the 'Environment — state and outlook 2010 Report', generally referred to as the SOER 2010[2]. Coordinated by the European Environment Agency, the SOER series is aimed primarily at policymakers, in Europe and beyond, involved with framing and implementing policies that could support environmental improvements in Europe. The information also helps European citizens to better understand, care for and improve Europe's environment. The soil assessment was one of a set of 13 Europe-wide thematic assessments of key environmental themes and the only one coordinated by the JRC.

This Reference Report includes additional material not included in the SOER, together with some supplementary information that was not available at the time of publication of the original text.

The report describes the knowledge and understanding of the state of soil in Europe and the main trends, outlook and policy responses for the key processes affecting soil resources in Europe. Unfortunately, our knowledge base on many of the key functions of soil that deliver vital environmental services and goods is still poorly developed. This aspect will be a key focus of the activities of JRC for the next SOER, foreseen for 2015.

The most pertinent issues and facts from the assessment are presented as Key Messages at the start of this report. Much more information and data can be found on the websites of the ESDAC (http://esdac.jrc.ec.europa.eu) or the JRC Soil Action (http://eusoils.jrc.ec.europa.eu).

This report, and more generally the work on soil carried out by the JRC, is in support of the European Commission's Soil Thematic Strategy (COM(2006) 231) and the proposed Soil Framework Directive (COM(2006) 232) which have the objective to protect soils across the EU and ensure their sustainable use.[3]

[1] http://www.eea.europa.eu/soer/europe/soil
[2] http://www.eea.europa.eu/soer
[3] More information on the Soil Thematic Strategy can be found under http://ec.europa.eu/environment/soil/index_en.htm

KEY MESSAGES

Soil is defined as the top layer of the Earth's crust. It is a natural substance composed of weathered rock particles (minerals), organic matter, water and air. A typical sample of mineral soil comprises 45% minerals, 25% water, 25% air and 5% organic matter – however, these proportions can vary. Soil is a habitat and gene pool, serves as a platform for human activities, landscape and heritage, and acts as a provider of raw materials. A healthy, fertile soil is at the heart of food security. These functions are worthy of protection because of their socio-economic as well as environmental importance.

Soil characteristics vary in depth and across the landscape. The above photograph shows a 120 cm section or profile that has been excavated in a soil that has developed in fine-grained silty sediments under a permanent cover of grass. Under the surface, this soil has a deep, dark layer or horizon (0-40 cm in the above photograph). This colouration is due to the presence of organic matter which has accumulated over time through the decay of leaves, roots and soil organisms. In most soils, the level of organic matter decreases with depth, hence the lighter soil colour below 40 cm in the above picture. Below 60 cm, there is very little evidence of soil-forming processes and the original geological material in which the soil has developed is very evident. Changes in the composition, appearance and thickness of the soils reflect the interplay between the main soil-forming factors - parent material (predominantly geological), climate, biology (plants and soil fauna), position in the landscape, time and human influences. The upper 30-40 cm of the soil is referred to as the topsoil, while the deeper parts are known as the subsoil. The soil in the above photograph is from Hungary and is known as a Chernozem. Characterised by their thick topsoil layer, Chernozems are some of the most naturally fertile soils on the planet. *© Erika Micheli*

Soil-forming processes tend to be slow and occur over long periods of time — typical rates of soil formation under permanent grasslands in temperate climates are in the order of only 1–2 cm per 100 years. Soil that is lost due to degradation processes (e.g. erosion, pollution) would need hundreds or thousands of years to recover naturally. Compared to the lifespan of human beings, soil loss is not recoverable which means that soil must be regarded as a non-renewable resource.

The soil resources of Europe are diverse. Relatively young soils dominate northern and central Europe. Soils in northern Europe tend to have higher organic matter content than those in the south. Poorly developed soils or soil with accumulations of calcium carbonate characterise the Mediterranean basin.

The unsustainable use and management of land is leading to increased soil degradation and the loss of a key resource that is fundamental to life on the planet.

Despite its importance for our society, and unlike air and water, there is no EU legislation specifically targeting the protection of soil. Different EU policies for water, waste, chemicals, industrial pollution, nature protection, pesticides and agriculture contribute indirectly to soil protection. However, as these policies have other aims, they are not sufficient to ensure an adequate level of protection for all soil in Europe. Furthermore, the prevention of soil degradation is also limited by the scarcity of data. In this context, the European Commission adopted a **Soil Thematic Strategy** (COM(2006) 231) and a proposal for a Soil Framework Directive (COM(2006) 232) with the objective to ensure a sustainable use of soils across the EU and to protect them from a series of key threats[4] that include:

- **Biodiversity decline**: soil biodiversity reflects the enormous variety of organisms, from bacteria to mammals, which shape the metabolic capacity of terrestrial ecosystems and many soil functions. Soil biodiversity is affected by all of the threats and degradation processes listed below and contribute to the loss of soil biodiversity.
- **Compaction** can be induced by the use of heavy machinery in agriculture. Compaction reduces the capacity of soil to store and conduct water, makes it less permeable for plant roots and increases the risk of soil loss by water erosion. Estimates of areas at risk of soil compaction vary. Some authors estimate that 36% of European subsoils have a high or very high susceptibility to compaction. Other sources report 32% of soils as being highly susceptible and 18% moderately affected.
- **Contamination**: due to more than 200 years of industrialisation, soil contamination is a widespread problem in Europe. The most frequent contaminants are heavy metals and mineral oil. The number of sites where potentially polluting activities have taken place now stands at approximately 3 million.
- **Erosion**: 105 million ha, or 16% of Europe's total land area (excluding Russia), were estimated to be affected by water erosion in the 1990s. 42 million ha are affected by wind erosion. A recent new model of soil erosion by water constructed by the JRC has estimated the surface area affected in EU-27 at 1.3 million km². Almost 20% is subjected to a soil loss in excess of 10 t/ha/yr.

4 More information on the Soil Thematic Strategy can be found at http://ec.europa.eu/environment/soil/index_en.htm

- **Landslides** can be triggered by factors such as land abandonment and land use change. They occur more frequently in areas with highly erodible soils or clay-based sub-soils on steeply sloping ground under intense and abundant precipitation. While there is no data on the total affected area in Europe, over 630,000 landslides are currently registered in national databases.
- **Organic matter decline**: organic matter is a key component of soil, controlling many vital functions. Some 45% of soils in Europe have a low or very low organic matter content (0–2% organic carbon). This is particularly evident in the soils of many southern European countries, but is also evident in parts of France, the United Kingdom, Germany, Norway and Belgium. A key driver is the conversion of woodland and grassland to arable crops. The soils of EU-27 Member States are estimated to store between 73 and 79 billion tonnes of carbon.
- **Salinisation** is the result of the accumulation of salts and other substances from irrigation water and fertilisers. High levels of salt will eventually make soils unsuitable for plant growth. It affects approximately 3.8 million ha in Europe. The main driver is the inappropriate management of irrigated agricultural land.
- **Sealing** occurs when agricultural or non-developed land is lost to urban sprawl, industrial development or transport infrastructure. It normally includes the removal of topsoil layers and leads to the loss of important soil functions, such as food production, water storage or temperature regulation. On average, built-up and other manmade areas account for around 4% of the total area in the countries of the European Economic Area (data exclude Greece, Switzerland and the United Kingdom), but not all of this is actually sealed. Between 1990 and 2000, at least 275 hectares of soil were lost per day in the EU, amounting to 1,000 km^2 / year. Between 2000 and 2006, the EU average loss increased by 3%, but by 14% in Ireland and Cyprus, and by 15% in Spain. In the period 1990-2006, 19 Member States lost a potential agricultural production capability equivalent to a total of 6.1 million tonnes of wheat, with large regional variations.

Climate change may worsen soil degradation and cause further desertification. Models indicate that the impact of global warming on evapotranspiration shows a sharp transition from slight increases (0.1–0.5 mm/day) in the north of Europe to reductions (of the order of − 0.5 mm/day) in Mediterranean areas. For all of central and northern Europe where soil moisture levels exceed 75% of the field capacity (the amount of water held in soil after excess water has drained away), evapotranspiration increases by about 0.3 mm/day. Unless suitable land management procedures are implemented, more frequent and more severe droughts will cause soil water retention mechanisms to collapse, leading to the onset of erosion and desertification.

Additional support is needed to continue and develop **research** projects, particularly in the understanding of the economic-social-environmental benefits of soil functions and the impact of degradation processes over time; initiatives to **raise awareness** in society as a whole of the value and importance of soil; and the consolidation of a harmonised approach to **soil monitoring** and data collection programmes.

1 INTRODUCTION

Soil is the unconsolidated mineral or organic material on the immediate surface of the Earth that serves as a natural medium for the growth of land plants. Soil displays the effects of genetic and environmental factors such as climate, living organisms and relief acting on parent material over a period of time. At its lower boundary, soil grades to hard rock or unconsolidated materials virtually devoid of any evidence of biological activity. For purposes of classification, the lower boundary of soil is generally set to 200 cm.

Soil is a vital natural resource that regulates our environment and responds to a range of pressures imposed upon it [1][5]. The soil resources of Europe are diverse (see Fig. 1). Due to climatic conditions, northern European soils tend to have higher organic matter content than those in the south. Relatively young soils, created and formed since the last the Ice Age dominate northern and central Europe. Poorly developed soils or soil with accumulations of calcium carbonate characterise large parts of the Mediterranean Basin. Soil underpins the delivery of a range of land-based ecosystem goods and services that support, provide and regulate life on the planet (Millennium Ecosystem Assessment, 2005). While this complex bio-geochemical system is best known as a medium that supports agricultural production and forests, soil is also a critical component of a diverse set of eco-processes from water management, terrestrial carbon fluxes, and land-based natural greenhouse gas production to nutrient cycles. Thus, human well-being and our economy depend on a multitude of critical ecosystem services and soil functions that include:

- Soil is the medium that enables us to grow food for people and animals, natural fibre, timber for fuel and construction, and supports wildlife. Around 99% of global food supplies (calories) for human consumption come from land-based food production (FAO, 2007).
- Soil provides the foundation on which we construct buildings, roads and other infrastructures. In addition to providing the support for the vast majority of human infrastructure, soil provides a range of raw materials such as clay for pottery and peat for fuel [2].
- Soil is a biological engine where dead plant and animal tissues, and other organic wastes, are decomposed to provide nutrients that sustain life. Soil is alive: decomposition processes are driven by a mass of soil microorganisms. A handful of soil may contain more than 10 billion microorganisms (Torsvik and Ovreas, 2002) — comparable to the number of people on Earth! While the majority of these microorganisms are bacteria, 1 m^3 of fertile topsoil can contain hundreds of kilometres of fungal hyphae, tens of thousands of protozoa, thousands of nematodes, several hundred insects, spiders and worms, and hundreds of metres of plant roots. The total weight of microorganisms in the soil below a hectare of temperate grassland can be more than five tonnes (e.g. a medium-sized elephant) and often exceeds the above-ground biomass. This biota is involved in most of the key functions of soil, driving fundamental nutrient cycling processes, regulating plant communities, degrading pollutants and helping to stabilise soil structure. Soil organisms represent a biotechnological resource, with many species of bacteria and actinomycetes providing sources of antibiotics and other medicines.
- Soil plays a crucial role in regulating a number of life-sustaining natural biological and chemical cycles (ecosystem services). Carbon, nitrogen and a range of essential nutrients are continuously recycled between the soil and plants, geological deposits, groundwater and the atmosphere. The intensity of these biogeochemical exchanges varies from place to place and is regulated by soil characteristics.

5 Numbers in square brackets refer to the Glossary/Supporting Information section that can be found at the end of the report.

- Soil is a natural filter that neutralises certain pollutants by transforming them or accumulating and absorbing their toxicity. Soil is a major factor in purifying water supplies. In addition, soil is a critical component in regulating flooding through the storage of rainfall since the sealing and compaction of permeable soils results in a more rapid delivery of rainfall to the river network.
- Soil protects our buried heritage of archaeological and historic remains from damage and depletion. Much of the evidence of past habitats and human heritage remains buried, awaiting discovery and study by archaeologists and palaeo-ecologists. The degree of preservation of such remains depends on the local soil characteristics and conditions [3]. Soils that preserve cultural heritage should also be regarded as valuable.

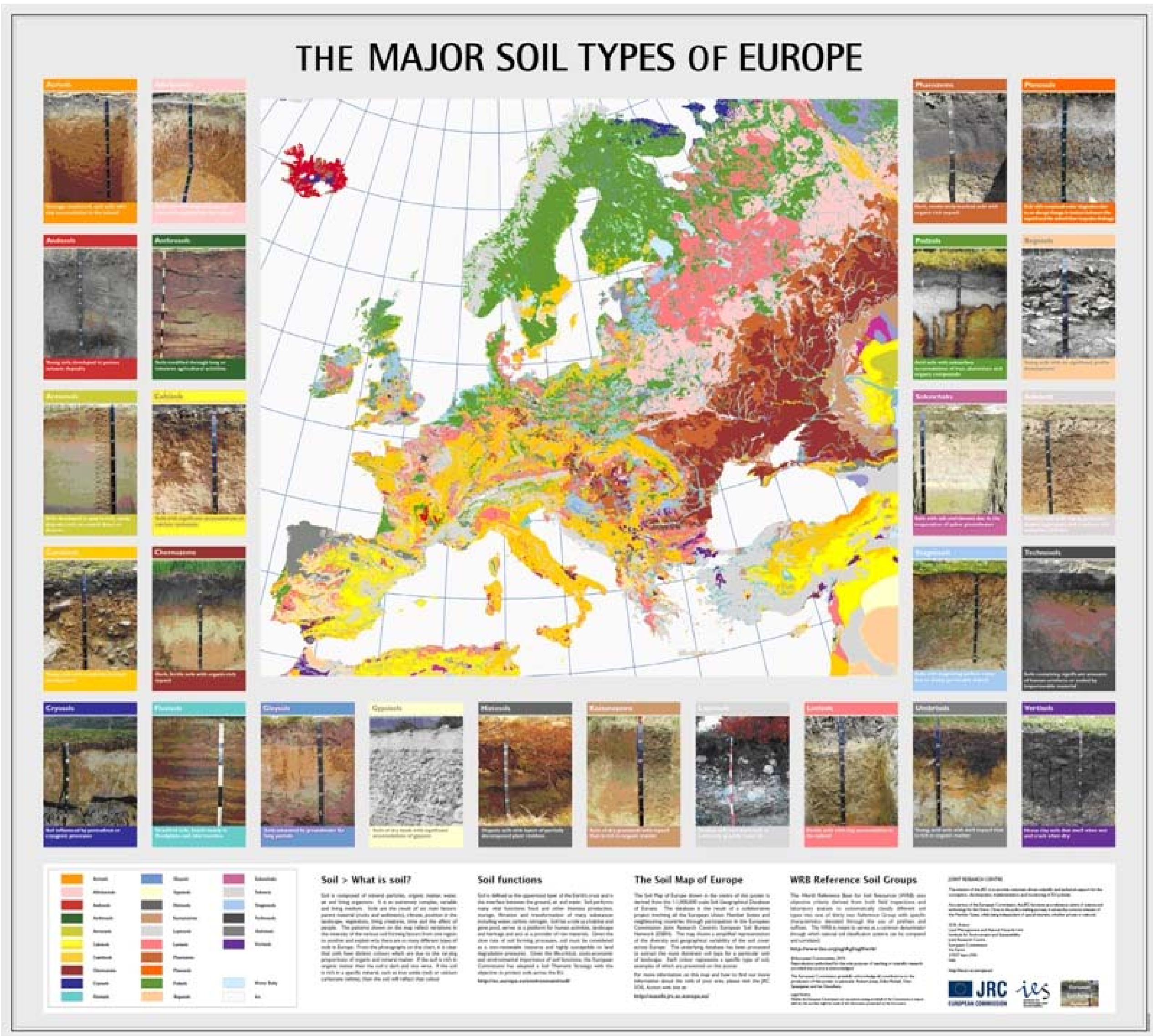

Figure 1: The major soil types of Europe [1b]. The colours on the map represent different soil types as depicted by the accompanying photographs. Much of northern and central Europe is characterised by young soils while lime-rich soils are common is southern territories. Scandinavia is almost completely covered by acidic Podzols. To the east, permanent grasslands dominate soil development. The red colour (e.g. Iceland) indicates soils on volcanic material. The light-blue colour denotes soils that are waterlogged for considerable parts of the year.

A copy of this poster can be downloaded from http://eusoils.jrc.ec.europa.eu/Awareness/SoilTypes.html

Source: JRC/ESDAC

2. STATE AND TRENDS

2.1 Soil functions

Soil underpins the delivery of a range of land-based services that support life on the planet (Fig. 2). However, soil functions occur out of sight under our feet and often involve microbial activity and chemical reactions. Subtle variations in soil characteristics over short distances can significantly affect how the soil operates due to soil complexity, spatial variability and scale issues. This can lead to uncertainties in making wide-ranging representative statements on the state of soil in general.

In some instances, the degradation of soil functions can be seen at the land surface. Examples include poor crop yields due to poor soil management or pools of standing water at the entrance to fields where the traffic of heavy agricultural machinery has led to subsoil compaction and impeded drainage. However, in most cases, evidence for the state of soil functions has to be collected painstakingly through intensive field sampling and laboratory analysis. The development of effective indicators for different soil functions is a challenge.

Another issue that hampers the pan-European assessment of the state of soil is the lack of a legal requirement to collect such information in a harmonised manner or even at all. While most European countries have mapped the soils on their territory that are used for agricultural and forest production, many of these surveys are now several decades old, not updated and not containing the data required to answer current questions such as their potential as carbon sinks, the impacts of pollutants on soil micro-fauna, the leaching of phosphorus due to over-fertilisation or the state of environmental functions. Some countries have detailed and wide-ranging soil monitoring networks which measure a number of parameters relating to soil quality. However, since many of these networks reflect national or regional priorities and standards, comparing their results with those of other countries is difficult. At the same time, many countries have no provision for the systematic collection of soil data.

Figure 2: Soils provide numerous life-critical, environmental and socio-economic functions: the most recognised is the production of food, fibre and wood. Without fertile soil, life as we know it would not be possible. *© Erika Micheli; Stephen Peedell*

Consequently, it is difficult to apply a bottom-up approach of collating reports from the individual countries to derive a harmonised evaluation for Europe. While there are increasing examples of soil-function maps at the local level, pan-European assessments are rare. As a result, many of the appraisals of soil functions at the European level are provided largely through models that make assumptions about the ability of specific soil types to provide certain functions. In a simplistic example, crops grown on sandy soils can suffer during periods of drought as the water storage capacity is low although these soils allow for the easy drainage of surface water. The converse is generally true for clay soils. However, all such models are simplifications of the real world, are data intensive and are still being refined.

2.2 Threats to soil

Widespread soil degradation, leading to a decline in the ability of soil to carry out its ecosystem services, is caused largely by non-sustainable uses of the land. This has also marked local, regional, European and global impacts. Soil degradation contributes to food shortages, higher commodity prices, desertification and ecosystem destruction. Society has a duty to ensure that the soil resources within their territories are managed appropriately and sustainably. The character of the major threats to soil has not changed significantly since the last SOER assessment in 2005 (EEA, 2005a). The following sections outline the state and trends of the main soil degradation processes in Europe and show that, while the situation is variable, many soil degradation processes are accelerating in many parts of Europe (EEA, 2005b), often exacerbated by inappropriate human activities and widely varying approaches to tackling degradation processes.

2.2.1 Organic matter content

Soil organic matter is essentially derived from residual plant and animal material, transformed (humified) by microbes and decomposed under the influence of temperature, moisture and ambient soil conditions. The stable fraction of soil organic matter is known as humus. Soil organic matter (SOM) plays a major role in maintaining soil functions because of its influence on soil structure and stability, water retention, soil biodiversity, and as a source of plant nutrients. The primary constituent of SOM is soil organic carbon [4].

- **State of soil organic carbon levels**: Around 45% of the mineral soils in Europe have low or very low organic carbon content (0–2%) and 45% have a medium content (2–6%) (Rusco *et al*., 2001). Figure 3 shows that low levels are particularly evident in the southern countries of Europe: 74% of the land in southern Europe is covered by soils that have less than 2% of organic carbon in the topsoil (0–30cm) (Zdruli *et al*., 2004). However, low levels of organic matter are not restricted to southern Europe as areas of low soil organic matter can be found almost everywhere, including in some parts of more northern countries such as France, the United Kingdom, Germany, Norway and Belgium.

  Excess nitrogen in the soil from high fertiliser application rates and/or low plant uptake can cause an increase in mineralisation of organic carbon which, in turn, leads to an increased loss of carbon from soils. Maximum nitrogen values are reached in areas with high livestock populations, intensive fruit and vegetable cropping, or cereal production with imbalanced fertilisation practices. While in extreme situations, the surplus soil nitrogen can be as high as 300 kg N ha^{-1} (EC, 2002)¸ estimates show that 15% of land in the EU-27 exhibits a surplus in excess of 40 kg N ha^{-1} (Fig. 4). As a reference to understand nitrogen surplus levels, the IRENA Mineral Fertiliser Consumption indicator (EEA, 2005a) estimates that, depending on the specific crop, the average rates of nitrogen fertiliser applications for EU-15 in 2000 ranged from 8–179 kg N ha^{-1}.

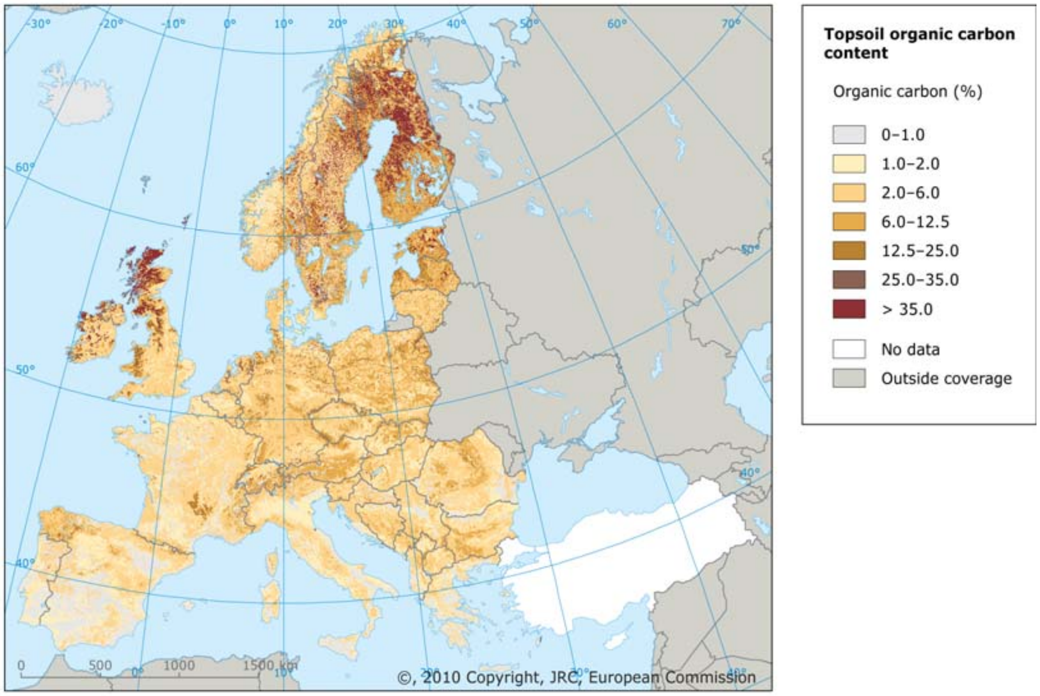

Figure 3: Variations in topsoil organic carbon content (%) across Europe. The darker regions correspond to soils with higher values of organic matter. The darkest colours, especially in Ireland, the United Kingdom, Estonia and Fennoscandinavia denote peatlands.

Source: JRC/Jones et al., 2005.

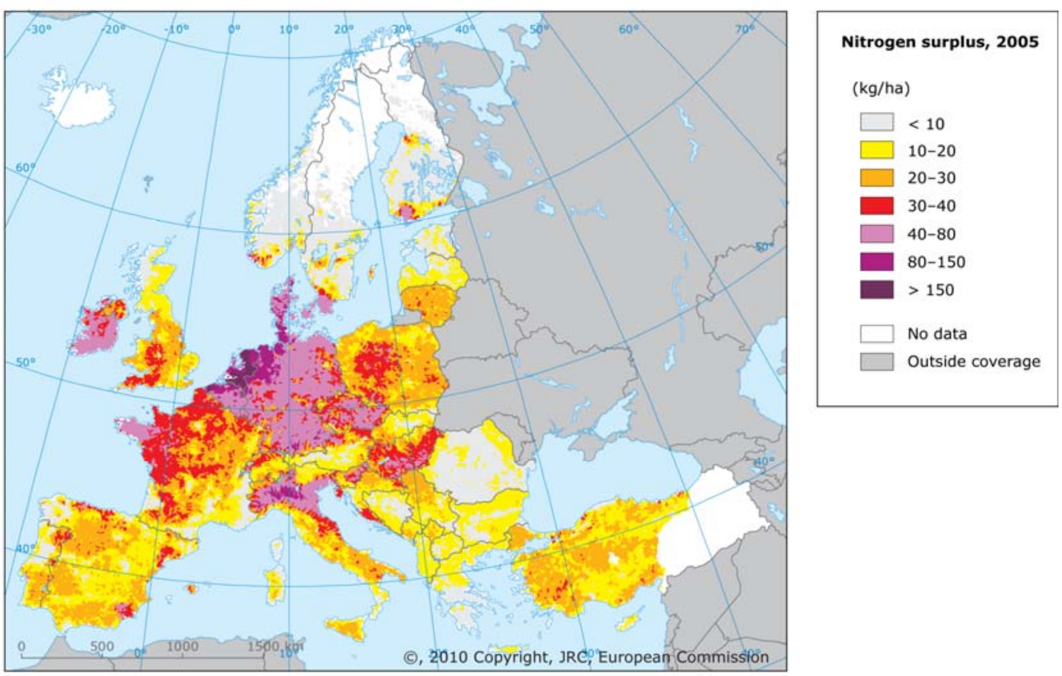

Figure 4: Estimated nitrogen surplus (the difference between inputs and uptake by crops, meat or milk production) for the year 2005 across Europe. Surplus nitrogen in the soil as a result of excessive application rates and/or low plant uptake can cause an increase in the mineralisation of organic carbon, which in turn, leads to an increased depletion of carbon from soils.

Source: JRC/Bouraoui et al., 2009.

There is growing realisation of the role of soil, in particular peat, as a store of carbon and its role in managing terrestrial fluxes of atmospheric carbon dioxide (CO_2). Other than in tropical ecosystems, soil contains about twice as much organic carbon as above-ground vegetation. Soil organic carbon stocks in the EU-27 are estimated to be between 73 to 79 billion tonnes, of which about 50% is to be found in the peatlands and forest soils of Sweden, Finland and the United Kingdom (Schils *et al*., 2008).

Figure 5: An organic soil or peat in Ireland. Unlike mineral soils, the parent material of peat is vegetation.

© Arwyn Jones

Peat soils contain the highest concentration of organic matter in all soils (Fig. 5) [5]. Peatlands are currently under threat from unsustainable practices such as drainage, clearance for agriculture, fires, climate change and extraction. The current area of peatland in the EU is estimated at more than 318 000 km^2, mainly in the northern latitudes. While there is no harmonised exhaustive inventory of peat stocks in Europe, the CLIMSOIL report (Schils *et al*., 2008) estimated that more than 20% (65 000 km^2) of all peatlands have been drained for agriculture, 28% (almost 90 000 km^2) for forestry and 0.7% (2 273 km^2) for peat extraction.

The EU funded Carbon-Nitrogen Interactions in Forest Ecosystems (CNTER) project assessed carbon fluxes and pools for 400 European forest sites and found that sequestration rates in the soils of central European forests were around 190 kg C ha^{-1} yr^{-1}, which converted to a European scale would be equivalent to around 13 million tonnes C yr^{-1} (Gundersen *et al*., 2006).

- **Trends in soil organic carbon levels:** Except for the rapid removal of SOC by erosion and landslides, changes in soil organic carbon (SOC) levels as a result of the intensification of agriculture, deforestation or conversion of grassland to arable land (and vice-versa) are slow processes. A comparison of laboratory analysis of soil samples is the only reliable method to indicate actual changes in organic matter. However, practical considerations in sampling and variations in laboratory techniques make assessments of changes in SOC levels difficult. In general, soils under permanent grassland and woodland would be expected to show gains in SOC content over time. Depending on the management practices, cultivated and other disturbed soils tend to loose SOC. Changes in SOC levels are expected to be more rapid in topsoil (0–30 cm) than in deeper soil. Comparisons of carbon stocks should always take into consideration the soil type and land management practices.

  Some recent studies suggest that SOC in European agricultural land is decreasing (Vleeshouwers and Verhagen, 2002; Sleutel *et al*., 2003). Bellamy *et al*. (2005) used data from the National Soil Inventory of England and Wales obtained between 1978 and 2003 to show that an average of 0.6% of the organic carbon content was lost per year from soils across England and Wales over that period, with some soils loosing up to 2 g kg^{-1} yr^{-1} (Fig. 6). Similar trends were observed in France, Belgium and Austria (Dersch and Boehm, 1997; Saby *et al*., 2008; Goidts *et al*., 2009). The rate of change appears to be proportional to the initial soil organic carbon content. Soil organic matter decline is also of particular concern in the Mediterranean region (Jones *et al*., 2005) where high temperatures and droughts can accelerate its decomposition.

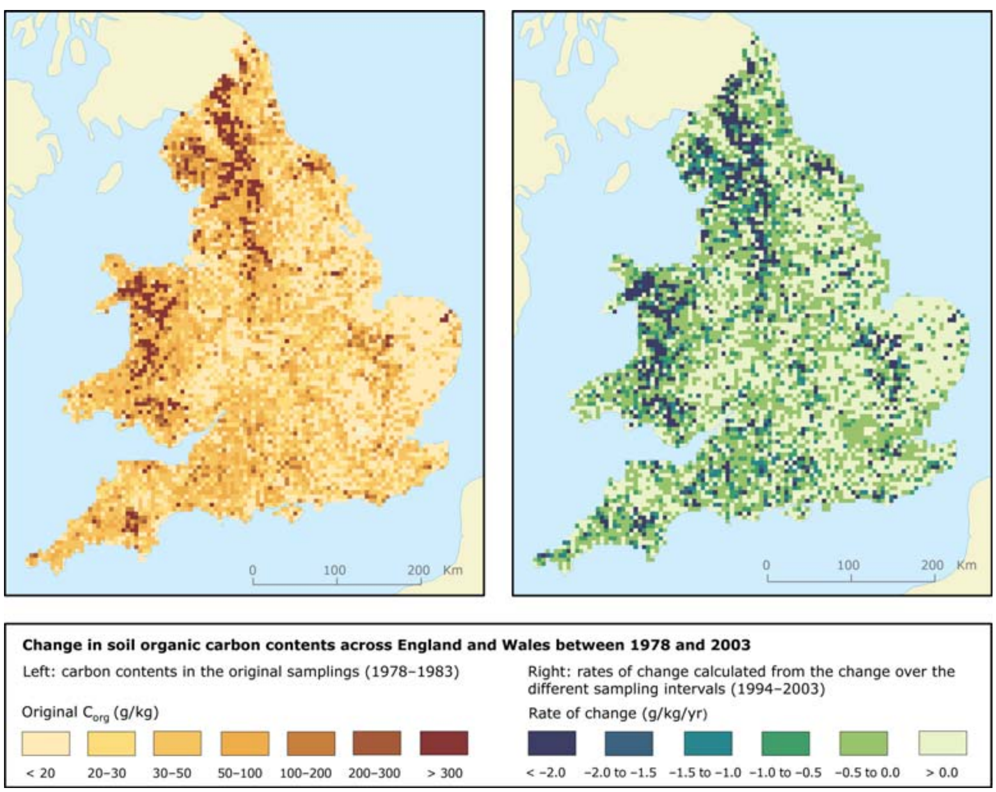

Figure 6: Changes in soil organic carbon content across England and Wales between 1978 and 2003. Source: Bellamy et al., 2005.

Several factors are responsible for a decline in SOM and many of them relate to human activity: conversion of grassland, forests and natural vegetation to arable land; deep ploughing of arable soils; drainage, fertiliser use; tillage of peat soils; crop rotations with reduced proportion of grasses; soil erosion; and wild fires (Kibblewhite *et al*., 2005). High soil temperatures and moist conditions accelerate soil respiration and thus increase CO_2 emissions (Brito *et al*., 2005).

Comparisons of results from the Biosoils project, carried out under the Forest Focus Regulation, with previous pan-European forest surveys provided new information on trends in soil organic carbon levels in European forests (Hiederer *et al.,* 2011). While analysis is complicated by differences in sampling and laboratory practices, several sites show a slight increase in the organic carbon stocks of forest soils over a 10 year interval.

2.2.2 Erosion

Erosion is the wearing away of the land surface by water [6] and wind [7], primarily due to inappropriate land management, deforestation, overgrazing, forest fires and construction activities. Erosion rates are very sensitive to climate, land use, soil texture, slope, vegetation cover and rainfall patterns as well as to detailed conservation practices at field level (Fig. 7). With the very slow rate of soil formation, any soil loss of more than 1 tonne per hectare per year (t ha^{-1} yr^{-1}) can be considered as irreversible within a time span of 50–100 years (Huber *et al*., 2008) [8]. However, the concept of variable tolerable rates of erosion should be noted and requires further definition (i.e. in some areas 1 t ha^{-1} yr^{-1} can be irreversible while in other regions, rates of 2-3 t ha^{-1} yr^{-1} can be sustained, given corresponding rates of soil formation).

Figure 7: Soil erosion by rill development on an agricultural field in the UK following an intensive rainstorm. Note that the eroded soil has been redeposited at the foot of the slope (brown area in the corner of the field). *© P. N. Owens*

- **State of soil erosion by water**

  Soil erosion by water is one of the most widespread forms of soil degradation in Europe [9] affecting an estimated 105 million ha, or 16% of Europe's total land area (excluding the Russian Federation; EEA, 2003). The Mediterranean region is particularly prone to water erosion because it is subject to long dry periods followed by heavy bursts of intense rainfall on steep slopes with fragile soils. In some parts of the Mediterranean region, erosion has reached a state of irreversibility and in some places erosion has practically ceased because there is no soil left. Soil erosion in northern Europe is less pronounced because of the reduced erosivity of the rain and higher vegetation cover. However, arable land in northern Europe is susceptible to erosion, especially loamy soils after ploughing (Bielders *et al*., 2003). One consequence of soil erosion is the transfer of nutrients from agricultural land to water bodies, which can result in the formation of toxic algal blooms.

  No harmonised measures of actual soil erosion rates exist for the European continent. Until recently, the only harmonised Europe-wide estimates of soil erosion by water were provided by the modelling-based exercsies such as the PESERA project (Gobin and Govers, 2003) [10]. However, issues with some input datasets gave rise to over- and under-estimates of erosion rates in certain conditions. Recent studies by the JRC (Bosco *et al*., 2012; Jones *et al.,* 2012; Fig. 8, Fig. 9) using the Revised Universal Soil Loss Equation (RUSLE) model and updated pan-European datasets indicated that mean rates of soil erosion by water in EU-27 were estimated to be 2.76 t ha^{-1} yr^{-1}; rates were higher in the EU-15 (3.1 t ha^{-1} yr^{-1}) than in the EU-12 (1.7 t ha^{-1} yr^{-1}) probably as EU-15 includes the Mediterranean area where overall erosion rates are higher. Several countries in the southern part of the EU show mean erosion rates that are significantly higher than the mean value for the EU. In addition, as shown in Fig. 8), just over 7% of cultivated land (arable and permanent cropland) in EU-24 (excluding Cyprus, Greece and Malta) is estimated to suffer from moderate to severe erosion (i.e. OECD definition of > 11 t ha^{-1} yr^{-1}). This equates to 115,410 km^2 or approximately the entire surface area of Bulgaria. In comparison, only 2% of permanent grasslands and pasture in EU-24 (excluding Cyprus, Greece and Malta) is estimated to suffer from moderate to severe erosion. This demonstrates the importance of maintaining permanent vegetation cover as a mechanism to combat soil erosion.

  Several researchers have reported soil erosion rates in Europe in excess of a critical 1 t ha^{-1} yr^{-1}. Arden-Clarke and Evans (1993) noted that water erosion rates in the United Kingdom varied from 1–20 t ha^{-1} yr^{-1} with the higher rates being rare events. Other researchers frequently found rates between 10 and 20 t ha^{-1} yr^{-1} in mainland Europe (Lal, 1989; Richter, 1983). Losses of 20 to 40 t ha^{-1} yr^{-1}in individual storms, which may happen once every two or three years, are measured regularly in Europe, with losses of more than 100 t ha^{-1} yr^{-1} occurring in extreme events.

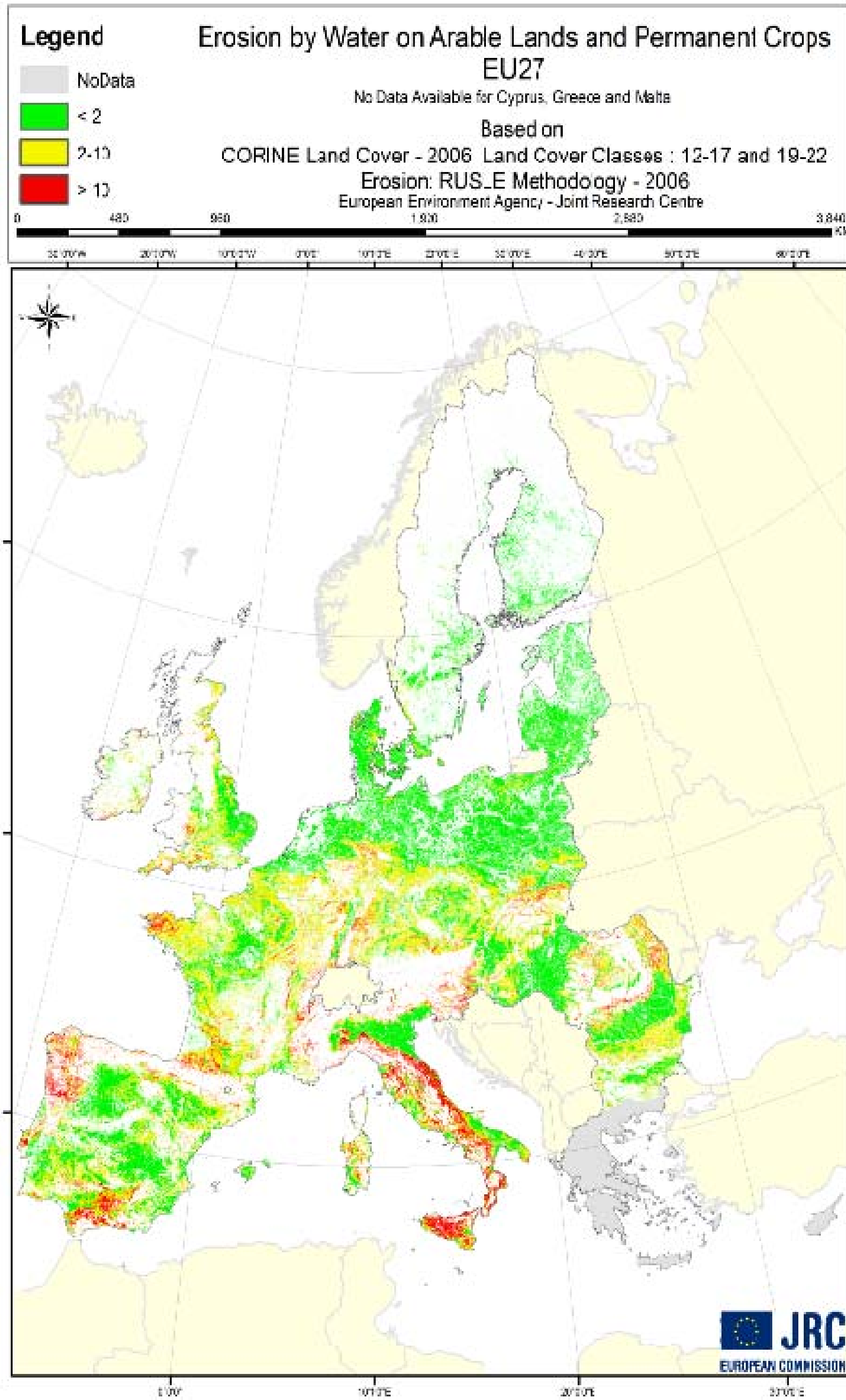

Figure 8: Estimation of soil erosion on cultivated land through rainsplash, sheetwash and rill erosion as calculated from the Revised Universal Soil Loss Equation (1 km grid cells) and CORINE 2006 Land Cover database. White areas are not considered as cultivated land in the Corine classification system.

Source: JRC/Bosco et al., 2012

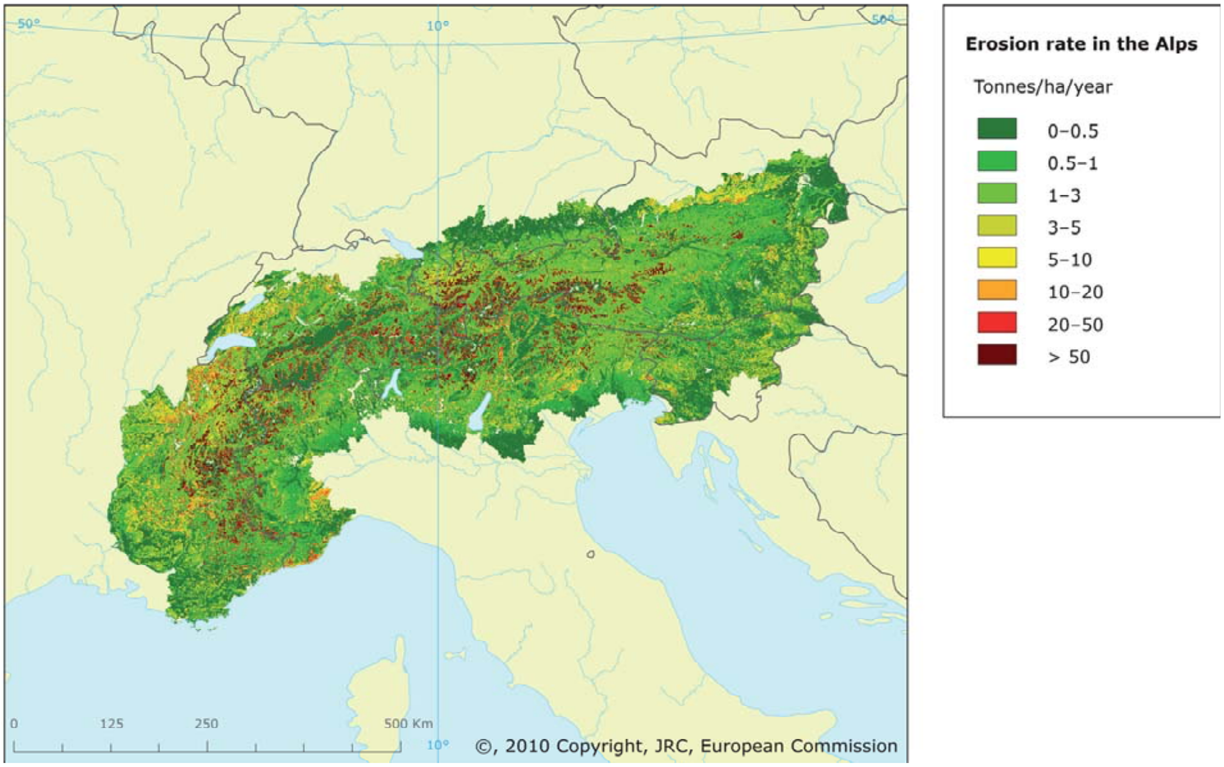

Figure 9: Erosion rate in the Alps. This map shows the predicted rate of soil erosion by water in the alpine territory. This map is derived from the Revised Universal Soil Loss Equation (RUSLE) model which calculates the actual sediment loss by soil erosion by taking into account rainfall erosivity, soil erodibility, slope characteristics, vegetation cover and land management practices aimed at erosion control. Areas at high risk of substantial soil erosion are shown by the orange and red colours (in this legend more than 10 t ha^{-1} yr^{-1}).

Source: JRC/ESDAC

- **State of soil erosion by wind**

  Wind erosion is a serious problem in many parts of northern Germany, eastern Netherlands, eastern England and the Iberian Peninsula. Estimates of the extent of wind erosion range from 10 to 42 million ha of Europe's total land area, with around 1 million ha being categorised as severely affected (Lal, 1994; EEA, 2003;). Recent work in eastern England reported mean wind erosion rates of 0.1–2.0 t ha^{-1} yr^{-1} (Chappell and Warren, 2003), though severe events are known to erode much more than 10 t ha^{-1} yr^{-1} (Böhner *et al*., 2003). In a similar study, Goossens *et al*. (2001) found values of around 9.5 t ha^{-1} yr^{-1} for arable fields in Lower Saxony, Germany. Breshears *et al*. (2003) researched the relative importance of soil erosion by wind and by water in a Mediterranean ecosystem and found that wind erosion exceeded water erosion in shrubland (around 55 t ha^{-1} yr^{-1}) and forest (0.62 t ha^{-1} yr^{-1}) sites but not on grasslands (5.5 t ha^{-1} yr^{-1}).

- **Trends in soil erosion by water and wind:** Assessing trends in soil erosion rates across Europe is difficult due to a lack of systematic approaches and data. However, a number of assumptions can be made. Given the close link with meteorological events and land cover, erosion rates and extent are expected to reflect changing patterns of land use and climate change. The SOER 2010 Assessment on Land Use (EEA, 2010b) presents statistics on trends in land-use patterns obtained from analysing changes in the Corine land cover datasets. The marked conversion of permanent pasture to arable crops and increasing demands for bioenergy, mostly from maize and other crops, are expected to lead to an increase in the risk and rates of soil erosion. As a result of climate change, variations in rainfall patterns and intensity may well result in increased erosion as droughts may remove protective plant cover while more intense rainfall events will lead to the physical displacement of soil particles.

2.2.3 Compaction

Soil compaction is a form of physical degradation due to the reorganisation of soil micro and macro aggregates, which are deformed or even destroyed under pressure. Compaction leads to a reduction in biological activity, porosity and permeability. Compaction can affect water infiltration capacity and increase erosion risk by accelerating run-off. A feature of compacted soils is the formation of a pan-layer that is less permeable for roots, water and oxygen than the soil below and is a bottleneck for the function of the subsoil. Topsoil compaction occurs when soil is subjected to pressure from the passage of heavy machinery or by repeated trampling of grazing animals, especially under wet conditions [11]. In arable land with annual cultivation, subsoil compaction is also possible by tractors driving directly on the subsoil during ploughing. Unlike topsoil, the subsoil is not loosened annually, and compaction becomes cumulative. As it occurs below the ground, soil compaction is very much a hidden problem.

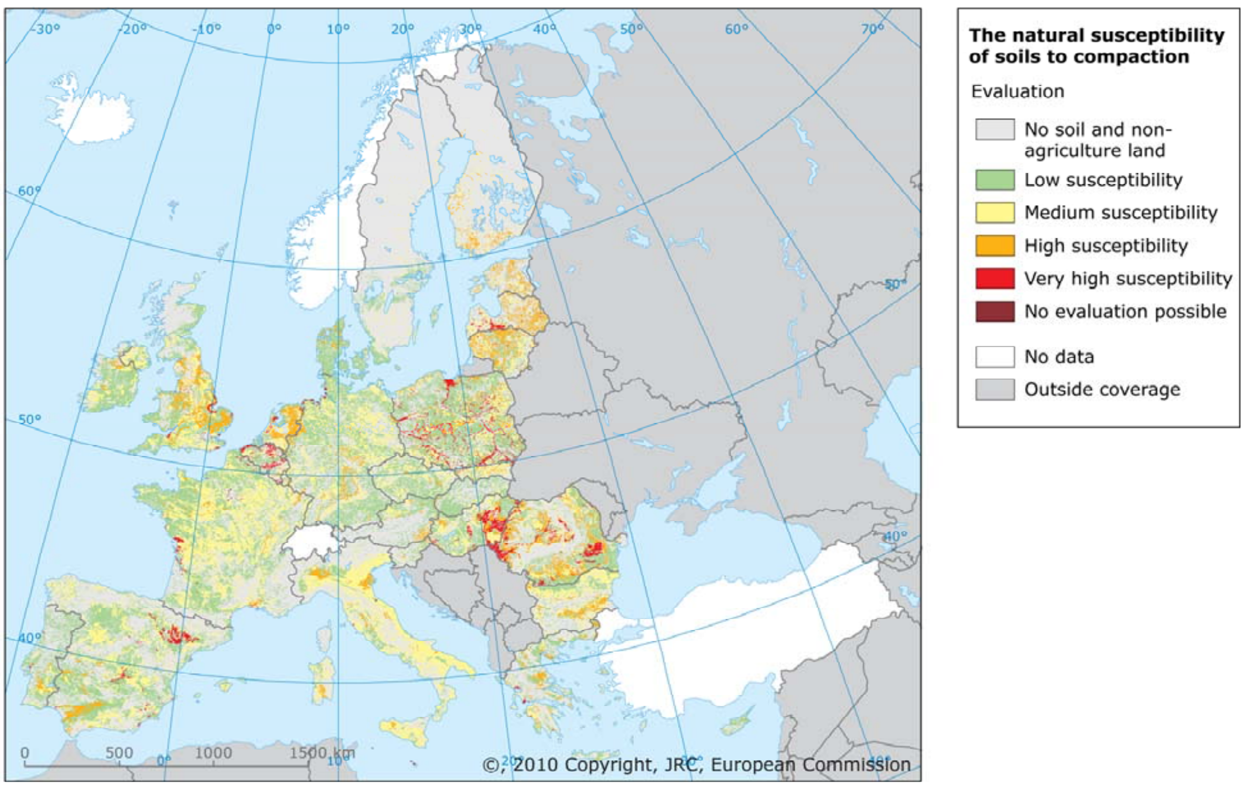

Figure 10: The natural susceptibility of soils to compaction. Susceptibility is the likelihood of compaction occurring if subjected to factors that are known to cause compaction. It does not mean that a soil is compacted.

Source: JRC/ESDAC

- **State of soil compaction:** Estimates of the area at risk of soil compaction vary. The sensitivity of soils to compaction depends on soil properties, such as texture and moisture, organic carbon content, and on several external factors such as climate and land use. Some researchers classify around 36% of European subsoils as having high or very high susceptibility to compaction (Van Camp *et al.,* 2004). Other sources report that 32% of soils are highly susceptible and 18% moderately affected by compaction (Crescimanno *et al.,* 2004). Again other sources estimate 33 million hectares being affected in total, corresponding to 4% of the European land surface (Van Ouwerkerk and Soane, 1995).

- **Trends in compaction:** Since the 1960s, the mechanisation of agriculture using heavy machinery has caused high stresses in the soil, even causing compaction deep in the subsoil below the plough layer (Van den Akker, 2004; Van den Akker and Schjønning, 2004). In recent years, arable farming techniques have improved (e.g. twin tyres, lower tyre pressures) in an attempt to minimize compaction, but overall the problem remains.

2.2.4 Soil sealing

Sealed soils can be defined as the destruction or covering of soils by buildings, constructions and layers of completely or partly impermeable artificial material (asphalt, concrete, etc. –Fig. 11). It is the most intense form of land take and is essentially an irreversible process. Sealing also occurs within existing urban areas through construction on residual inner-city green zones.

Figure 11: In most instances, soil sealing completely prevents natural soil functions, often irreversibly.
© Arwyn Jones

- **State of soil sealing**: On average, built-up and other manmade areas account for around 4% of the total area in EEA countries (data exclude Greece, Switzerland and United Kingdom), but not all of this is actually sealed (EEA, 2009). Member States with high sealing rates over the period 2000-2006 exceeding 5% of the national territory are Malta, the Netherlands, Belgium, Germany and Luxembourg (Prokop *et al.,* 2011).The EEA has produced a high resolution soil sealing layer map for the whole of Europe for the year 2006 based on the analysis of satellite images. Much more detail can be found in the SOER Assessments on the Urban Environment (EEA, 2010a) and Land Use (EEA, 2010b) , as well as in Prokop *et al.* (2011).

- **Trends in soil sealing**: Productive soil continues to be lost to urban sprawl and transport infrastructures. Between 1990 and 2000, the sealed area in the EU-15 increased by 6% (see Fig. 12) and at least 275 hectares of soil were lost per day in the EU, amounting to 1,000 km² / year (Prokop *et al.*, 2011). Between 2000 and 2006, the EU average loss increased by 3%, but by 14% in Ireland and Cyprus, and by 15% in Spain year (Prokop *et al.*, 2011). Huber *et al*. (2008) provides an interesting insight into the development of baselines and thresholds to monitor soil sealing. See also the SOER 2010 Assessment on Land Use (EEA; 2010b) for additional details on urbanisation.

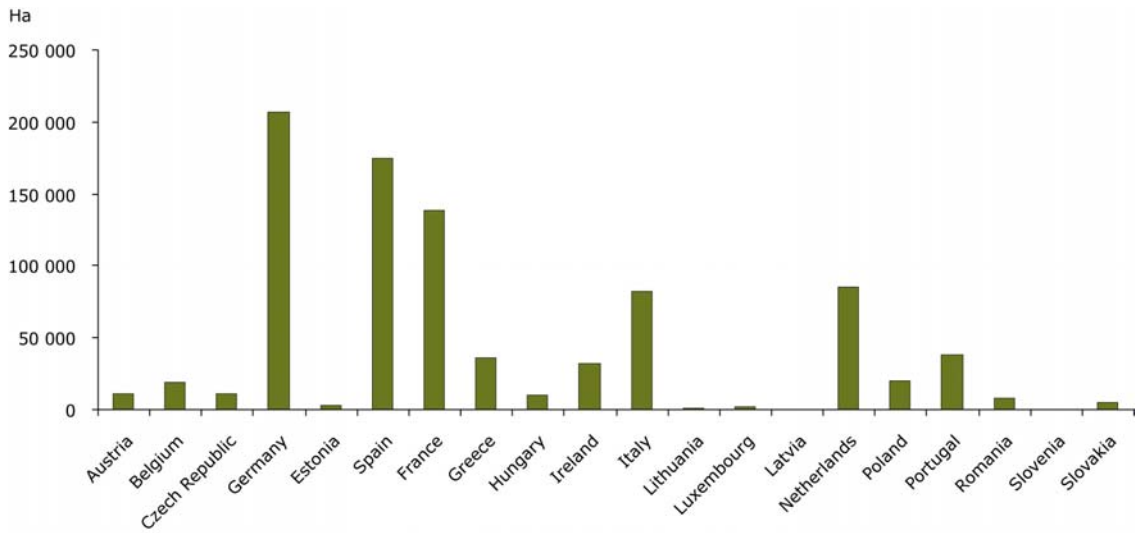

Figure 12a: Losses of agricultural areas to urbanisation (ha). Comparison of CORINE land cover data for 1990 and 2000 shows an estimated loss of 970 000 ha of agricultural land due to urbanisation for 20 EU Member States in this ten year period. The rate of change is not the same across all countries. It should be noted that non-agricultural land is also consumed by urbanisation. These trends continue in the period 2000–2006 as shown in the SOER 2010 Assessment on Land Use (EEA, 2010b).

Source: JRC/Gardi et al., 2009b

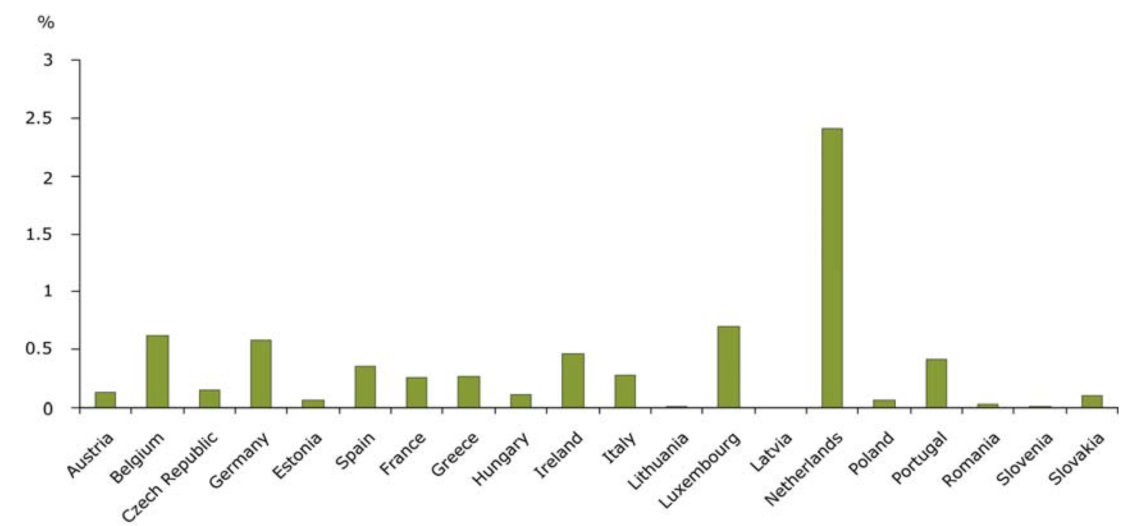

Figure 12b: Relative losses of agricultural areas to urbanisation (%) based on a comparison of CORINE land cover data for 1990 and 2000. The change in the Netherlands is dramatic, probably reflecting the intense demand on space and economic growth during the period in question.

Source: JRC/Gardi et al., 2009b

2.2.5 Salinisation

The accumulation of salt in soil is commonly referred to as salinisation. While naturally saline soils exist in certain parts of Europe, the main concern is the increase in salt content in soils resulting from human interventions such as inappropriate irrigation practices (Fig. 13), use of salt-rich irrigation water and/or poor drainage conditions. Locally, the use of salt for de-icing can be a contributing factor. The primary method of controlling soil salinity is to use excess water to flush the salts from the soil (in most cases where salinisation is a problem, this must inevitably be done with high quality irrigation water) [12].

- **State of salinisation:** Thresholds to define saline soils are highly specific and depend on the type of salt and land use practices (Huber *et al*., 2008). Excess levels of salts are believed to affect around 3.8 million ha in Europe (EEA, 1995). While naturally saline soils occur in Spain, Hungary, Greece and Bulgaria, artificially induced salinisation is affecting significant parts of Sicily and the Ebro Valley in Spain and more locally in other parts of Italy, Hungary, Greece, Portugal, France, Slovakia and Romania.

- **Trends in salinisation:** While several studies show that salinisation levels in soils in countries such as Spain, Greece and Hungary are increasing (De Paz *et al*., 2004), systematic data on trends across Europe are not available.

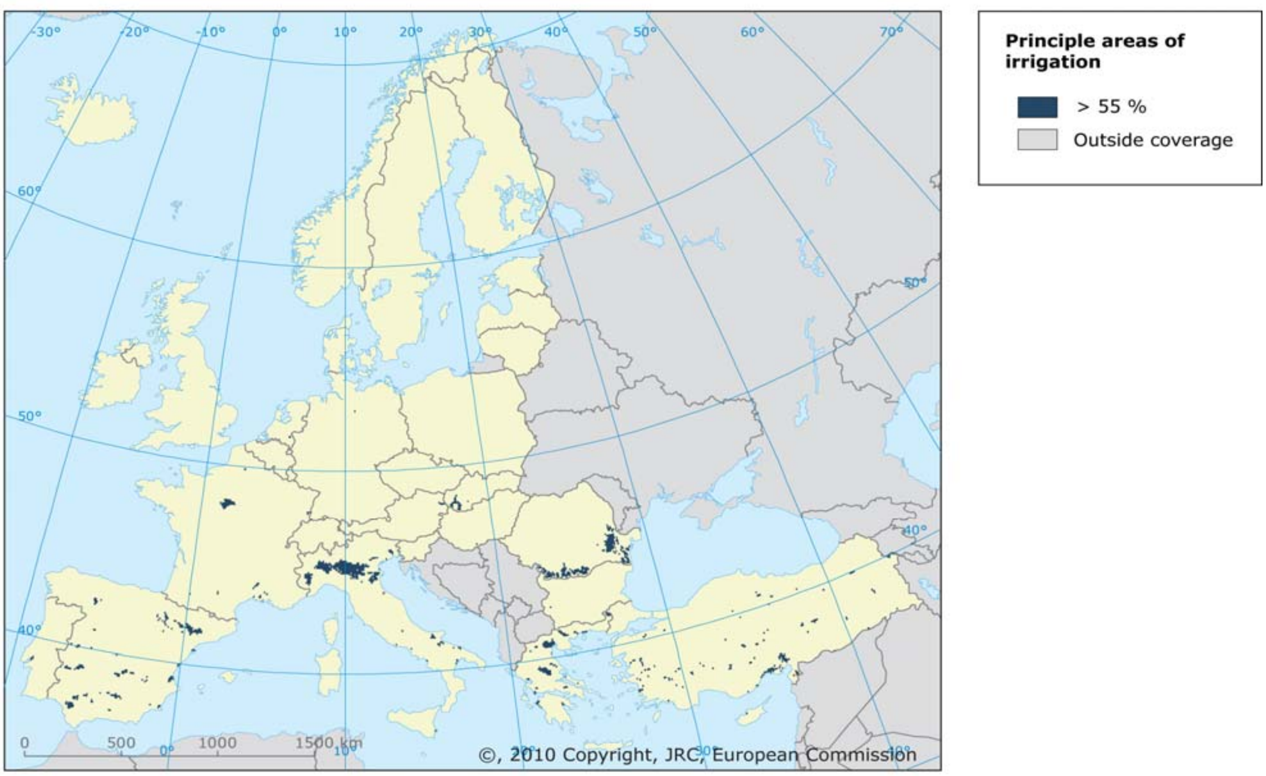

Figure 13: Principle areas of irrigation. This map shows irrigation intensity as a % of 10 km × 10 km cells. The build up of salts in soil can occur over time wherever irrigation occurs as all water contains some dissolved salts. When crops use the water, the salts are left behind in the soil and eventually begin to accumulate unless there is sufficient seasonal rainfall (usually in the winter months) to flush out the salts. The dark blue regions indicate the main areas of irrigation across Europe, zones that are susceptible to the accumulation of salts in the soil.

Source: FAO/AQUASTAT; Mulligan et al., 2006, map produced by the JRC/ESDAC

2.2.6 Acidification

Acidification describes the loss of base cations (e.g. calcium, magnesium, potassium, sodium) through leaching and replacement by acidic elements, mainly soluble aluminium and iron complexes [13]. Acidification is always accompanied by a decrease in a soil's capacity to neutralise acid, a process which is naturally irreversible when compared to human lifespans. In addition, the geochemical reaction rates of buffering substances in the soil are a crucial factor determining how much of the acidifying compounds are neutralized over a certain period. Acidifying substances in the atmosphere can have natural sources such as volcanism. However, the most significant ones in the context of this assessment are those that are due to anthropogenic emissions, mainly the result of fossil fuel combustion (e.g. in power plants, industry and traffic) and due to intensive agricultural activities (emissions of ammonia, NH_3) (Tuovinen *et al.*, 1994). Emissions of sulphur dioxide (SO_2) and nitrogen oxides (NO_X) to the atmosphere increase the natural acidity of rainwater, snow or hail. This is due to the formation of sulphuric and nitric acid (H_2SO_4, HNO_3), both being strong acids. Ammonia contributes to the formation of particulate matter in the air, including ammonium (NH_4). After deposition to ecosystems, the conversion of NH_4 to either amino acids or nitrate (NO_3) is an acidification process. Furthermore, forestry and agriculture (due to biomass harvest) can lead to ecosystem acidification processes in soils. Such conditions can be found in the heathlands of north-western Europe where land management practices over centuries have led to soil acidification and erosion[6].

- **State of soil acidification:** While a number of studies have produced reports of soil pH across Europe (Salminen *et al*., 2005; JRC, 2008), the systematic monitoring of soil acidification across Europe is generally lacking for non-forested soils. The EU Environmental Action Plans have a long-term objective of not exceeding critical loads of acidity in order to protect Europe's ecosystems from soil and water acidification. Though the interim environmental objective for the year 2010 has strictly speaking not been met, the improvements are considerable (see the SOER 2010 Assessment on Air Pollution (EEA, 2010c)). Soil acidification is closely linked to water acidification and indicators of critical loads [14] can be used to show the exposure of soils to acidification. Assuming full implementation of current policies in 2010, critical load models show that 84% of European grid cells which had exceedances in 1990 show a decline in exceeded area of more than 50% in 2010 (EEA, 2010h). However, a recent assessment of 160 intensive forest monitoring plots showed that critical limits for soil acidification were substantially exceeded in a quarter of the samples (Fischer *et al*., 2010).

- **Trends in acidification:** As a result of regulation and improved practices, emissions of acidifying pollutants, particularly of SO_2, have fallen in recent years (see the SOER 2010 Assessment on Air Pollution, EEA ,2010c; Fig. 14). A number of local and regional studies have shown that the impact of emission reduction schemes in many parts of the United Kingdom, Germany and Scandinavia is particularly evident with acid levels declining, rapidly in some parts, or at least stabilising (Ruoho-Airola *et al*., 1998; Fowler *et al*., 2007; Kowalik *et al*., 2007; Carey *et al*., 2008, EEA 2010h). However, a recent assessment of 160 ICP-Forest intensive forest monitoring plots showed that between 2000 and 2006 there was little change in soil acidification on the plots studied (Fischer *et al*., 2010). In many areas, NO_X and NH_3 are now identified as the main acidifying agents.

[6] Removal of native tree cover by clearance, grazing and burning results in the interruption of nutrient recycling from leaf fall and root uptake; eventually resulting in a loss of nutrients from the soil. These nutrient-poor soils became further acidified by organic acids leached from heather vegetation that replaces the trees. Continued removal of heather during the medieval period led to further nutrient depletion, acidification and soil degradation until today most heathlands are characterised by highly acidic soils (e.g. Podzols).

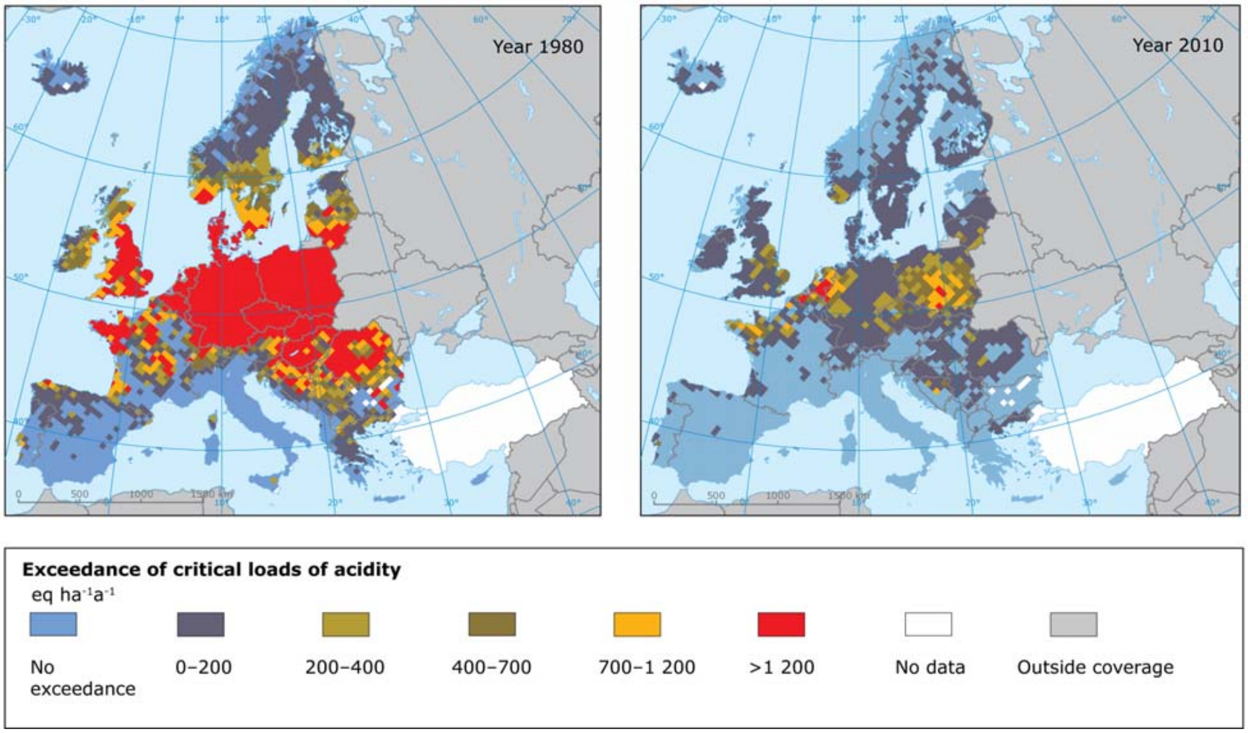

Figure 14: Maps showing changes in the extent to which European ecosystems are exposed to acid deposition (i.e. where the critical load limits for acidification are exceeded). In 1980, areas where critical loads of acidity were exceeded (shaded red) covered large parts of Europe. By 2010, this area had shrunk significantly. These improvements are expected to continue to 2020, although at a reduced rate.

Source: Deposition data collected by European Monitoring and Evaluation Programme (EMAP).

Maps drawn by Coordination Centre for Effects (CCE); EEA, 2010h.

2.2.7 Soil biodiversity

Soil biodiversity reflects the mix of living organisms in the soil (Fig. 15). These organisms interact with one another and with plants and small animals forming a web of biological activity. Soil is by far the most biologically diverse part of Earth. Soil biota play many fundamental roles in delivering key ecosystem goods and services, such as releasing nutrients from SOM, forming and maintaining soil structure and contributing to soil water entry, storage and transfer (Lavelle and Spain, 2001). Soil biodiversity is defined by the variation in soil life, from genes to communities, and the variation in soil habitats, from micro-aggregates to entire landscapes (UN, 1992; EEA, 2010g). Hence, soil degradation by erosion, contamination, salinisation and sealing all threaten soil biodiversity by compromising or destroying the habitat of the soil biota. Management practices that reduce the deposition or persistence of organic matter in soils, or bypass biologically-mediated nutrient cycling also tend to reduce the size and complexity of soil communities. It is however notable that even polluted or severely disturbed soils still support some level of microbial diversity. Specific groups may be more susceptible to certain pollutants or stresses than others, for example nitrogen fixing bacteria that are symbiotic to legumes are particularly sensitive to copper; colonial ants tend not to prevail in frequently-tilled soils due to the repeated disruption of their nests; generally, soil mites are a very robust group.

Figure 15: A healthy soil depends on a vibrant range of life forms living below the ground, from bacteria and fungi to insects, earthworms and moles. Together, this rich assemblage of life brings immeasurable benefits to the planet we live on. The images above provide a sample of life in the soil. They include from left to right:
***1st row** – alga of species Dictyococcus cf. varians (B. P. Skowrońska); collembola (J. Mourek); fungus of species Amanita muscari (K. Ritz); root nodules containing symbiotic bacteria (K. Ritz). **2nd row** – predatory nematode of genus Monochoides (H. van Megen); earthworms mating (M. Bartlett); winged queen ants of species Messor structor (A. Mori, D. Grasso); termite of species Reticulitermes lucifugus (E. Chiappini). **3rd row** – testate amoeba (K. Ritz); protozoa of species Bresslauides discoldeus (W. Foissner); surface dwelling soil mite (U. Tartes). **4th row** – fruiting bodies of a myxomycete (slime mould) (KF); millipede of species Narceus americanus (J. Mourek); scorpion of species Heterometrus longimanus (PDI). **5th row** – soil mite of species Hypoaspis aculeifer attacking an enchytraeid (T. Moser); carabid beetle (P. Brandmayr); isopod of species Porcello dilatatus (R. Innocenti).*

Source: JRC/Jeffery et al., 2010

- **State and trends of soil biodiversity**: Little is known about how soil life reacts to human activities but there is evidence that soil organisms are affected by SOM content, the chemical characteristics of soils (e.g. pH, the amount of soil contaminants or salts) and the physical properties of soils such as porosity and bulk density, both of which are affected by compaction or sealing. However in the last years, several studies on soil biodiversity have been started, allowing a better comprehension of the biogeography of soil organisms (Dequiedt *et al*., 2009; Cluzeau *et al*., 2009; Griffiths *et al*., 2011). Other recent research has targeted the investigation of the relationships between soil parameters, land management practices and soil biodiversity patterns (Gardi *et al*., 2008; Bru *et al*., 2011; Dequiedt *et al*., 2011; Keith *et al*., 2011), while other investigations are more focused on the contribution of soil biota to the provision of ecosystem services (Mulder *et al*., 2011). Despite these individual initiatives, one of the major differences between above-ground and below-ground biodiversity is that a majority of soil organisms are still unknown (see Table 1). For instance, it has been estimated that the currently described fauna of nematoda, acari and protozoa represent less than 5 % of the total number of species (Wall *et al*., 2001).

Table 1: Estimated global number of above-ground and below-ground organisms.

Group	Organism	Known	Known (%)
Plants	Vascular Plants	270 000	84
	Earthworms	3 500	50
Micro-fauna	Mites	45 231	4
	Springtails	7 617	15
Meso-fauna	Protozoa	1 500	7.5
	Nematodes	25 000	1.3
Micro-organisms	Bacteria	10 000	1
	Fungi	72 000	1
Marine species	All marine organisms	230 000	30

Source: Adapted from De Deyn and Van der Putten (2005), Wall *et al*. (2001)

Monitoring programmes are essential for the understanding of trends in soil biodiversity; within the EU several initiatives are currently running at national (Countryside Report, UK; ECOMIC-RMQS, France; BISQ, the Netherlands; CreBeo, Ireland; etc.) or regional level. Some of the ongoing initiatives at European level have been described by Gardi *et al*. (2009a).

A limited number of data concerning the dynamics of soil biodiversity are available, and these generally refer to a few groups of soil organisms (Fig. 15-18). Mushrooms, for instance, are a group of soil organisms for which a relatively long history of records exists. From this type of dataset, it has been possible to show mushroom species decline in some European countries. For example, a 65% decrease in mushroom species over a 20-year period has been reported in the Netherlands, and the Swiss Federal Environment Office has published the first ever 'Red List' of mushrooms detailing 937 known species that face possible extinction in Switzerland (Swissinfo, 2007).

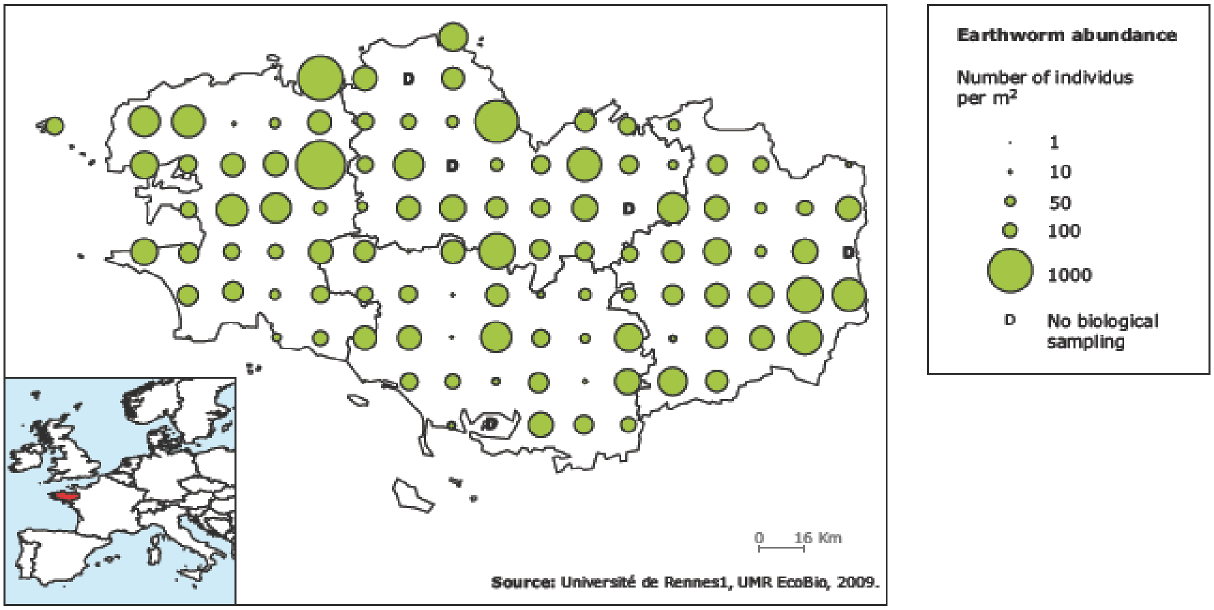

Figure 16: Estimate of earthworm abundance in Brittany. Higher numbers of earthworms (individuals / m^2) are found under grasslands with intermediate levels in croplands. Lower levels are typical of forest.

Source: Cluzeau et al., 2009

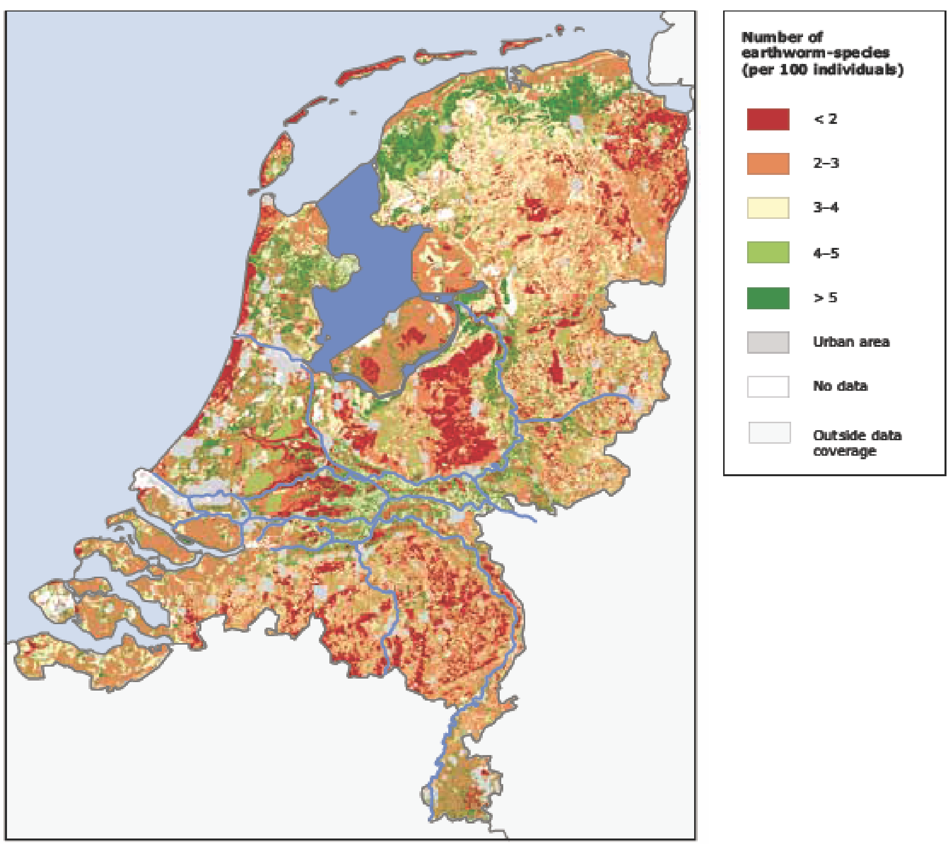

Figure 17: Earthworm species diversity in the Netherlands. Similarly to the previous example from France, the map shows that higher levels of earthworm diversity are found under pasture (grasslands on clay soils) with lower levels in forests (sandy soils).

Source: Rijksinstituut voor Volksgezondheid en Milieu (RIVM); Rutgers, 2010

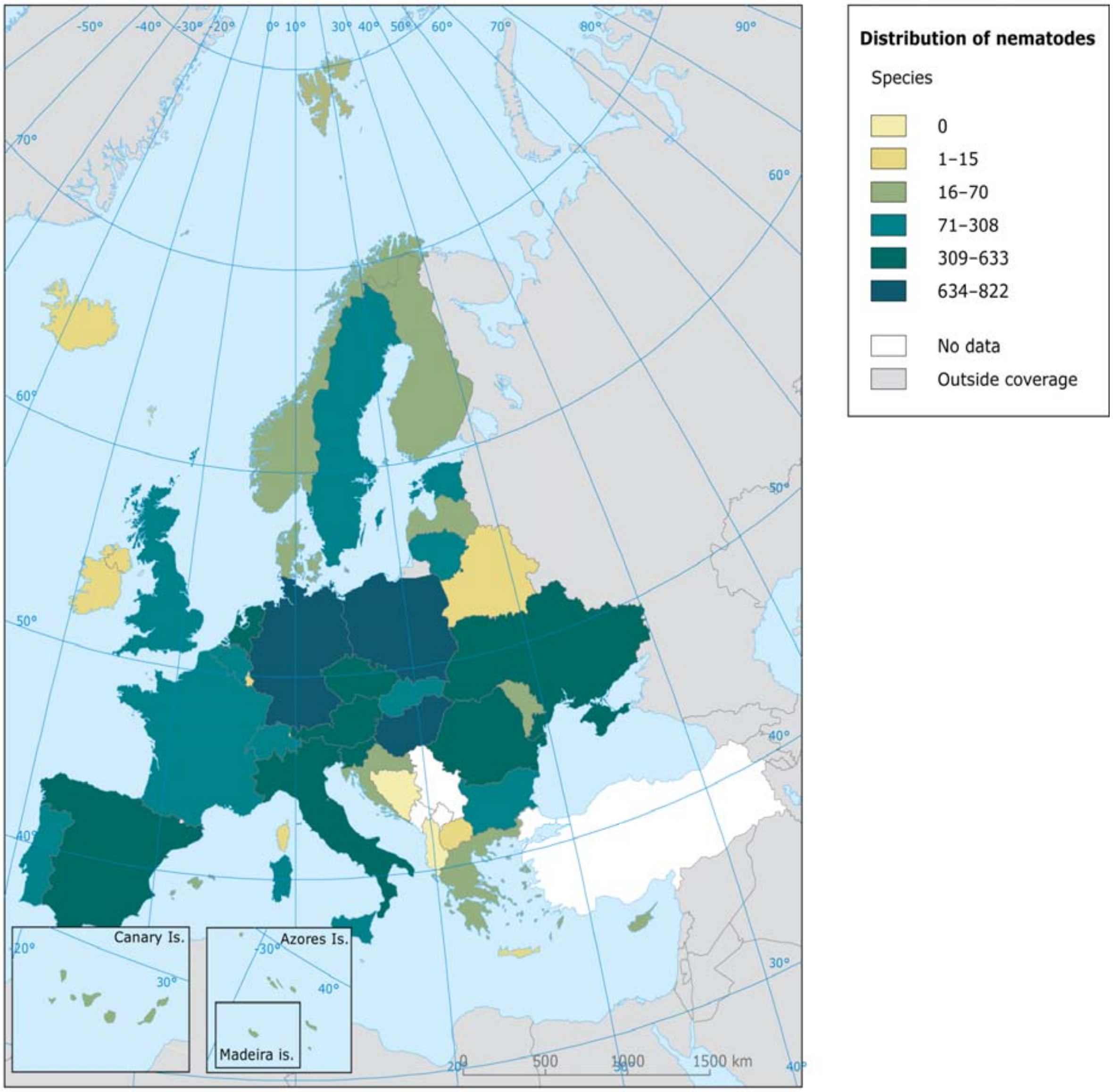

Figure 18: Map denoting the distribution of nematodes across Europe. It should be noted that such maps show the estimated number of species in certain biogeographic areas or countries and are indicative only as low values may also be due to lack of observations or evidence.

Source: Data provided from Fauna Europaea, www.faunaeur.org; Map produced by JRC/Jeffery et al., 2010

2.2.8 Desertification

Prolonged droughts and more irregular precipitation, combined with unsustainable use of water and agricultural practices, could lead to desertification, defined by the United Nations Convention to Combat Desertification (UNCCD) (UN, 1994) as 'land degradation in arid, semi-arid and dry sub-humid areas resulting from various factors, including climatic variations and human activities'. The most recent terminology adopted by the UNCCD includes areas suffering from 'Desertification, Land Degradation and Drought' and reflects the wider endorsement of the Convention by countries that do not have drylands within their national territories. Within the EU, Bulgaria, Cyprus, Greece, Hungary, Italy, Latvia, Malta, Portugal, Romania, Slovakia, Slovenia and consider themselves affected by desertification and are included in the Annex V of the UNCCD (UN, 2001).

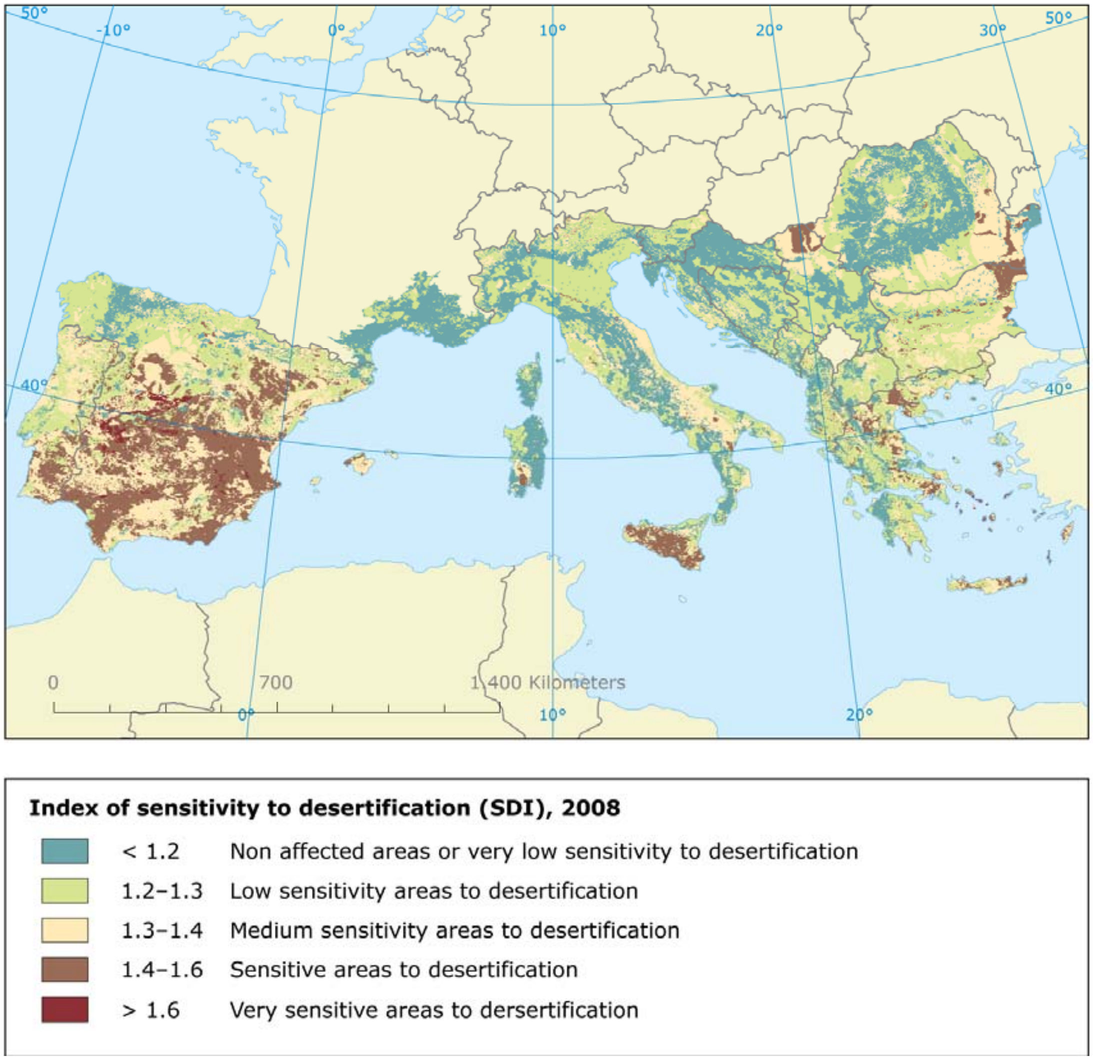

Figure 19: Map from the DISMED project (Desertification Information System for the Mediterranean) showing the sensitivity to desertification and drought as defined by the sensitivity to desertification index (SDI) based on soil quality, climate and vegetation parameters.

Source: Domingues & Fons-Esteve, 2008.

- **State of desertification:** The DISMED assessment (Domingues and Fons-Esteve, 2008) has shown that sensitivity to desertification and drought is lower in Europe than in neighbouring regions (Fig 19). The situation is most serious in southern Portugal, much of Spain, Sicily, south-eastern Greece and the areas bordering the Black Sea in Bulgaria and Romania. In southern, central and eastern Europe 8% of the territory currently shows very high or high sensitivity to desertification, corresponding to about 14 million ha, and more than 40 million ha if moderate sensitivities are included [15].
- **Trends in desertification:** Many soil types in the Mediterranean region already exhibit many aspects of degradation (i.e. low SOC content, prone to erosion, low fertility) which, together with the hot, dry climate of the region, hampers the recognition of desertification. While qualitative evidence for desertification appears to be prevalent throughout the region (e.g. increasing aridity, declining ground water levels), some recent observations suggest that the western Mediterranean is showing signs of a slight warming and of drier conditions while eastern parts are experiencing cooler, wetter conditions. However, other studies report opposing trends (Safriel, 2009).

2.2.9 Landslides

Landslides are the gravitational movement of a mass of rock, earth or debris down a slope (Cruden, 1991; Fig. 20) [16]. Landslides occur when the stability of a slope changes from a stable to an unstable condition. Such changes can be caused by a number of factors, acting together or alone. Natural causes of landslides include groundwater pressure, loss of vegetation cover (e.g. after a fire), erosion of the toe of a slope by rivers or ocean waves, saturation by snowmelt or heavy rains and earthquakes. Human causes include deforestation and removal of vegetation cover, cultivation, construction and changes to the shape of a slope. Landslides can be slow moving or very rapid.

Figure 20: Landslide scar in Veneto Italy. © Javier Hervás

- **State of landslides:** There are no data on the total area affected in Europe, although estimates have been made for Italy (7%), Portugal (1%), Slovakia (5%) and Switzerland (8%). The main landslide-prone regions include mountain ranges such as the Alps, Apennines, Pyrenees, Betics, Carpathians, and Balkans; hilly areas on landslide- sensitive geological formations for example in Belgium, Portugal and Ireland; coastal cliffs and steep slopes for example in the United Kingdom, France, Bulgaria, Norway and Denmark; and gentle slopes on quick clay in Scandinavia. Landslides are possibly the most serious environmental issue in Italy. [17: See dramatic images of major landslides in Calabria (Italy), Cornwall (UK) and Ireland].

  The development and harmonisation of national landslide inventories should be a priority to serve as a database for research into causes, susceptibility and risk zoning and potential remedial action. Many countries are creating comprehensive nationwide or regional landslide databases. So far European national databases contain more than 630 000 landslides but the true number of landslides in each country is certainly much higher, e.g. Italy (> 485 000), Austria (> 25 000), Slovakia (> 21 000), Norway (> 19 500), the United Kingdom (> 15 000), Czech Republic (> 14 000), Poland (> 12 000), France (> 10 000), Slovenia (> 6 600), Iceland (> 5 000), Greece (> 2 000) and Bosnia and Herzegovina (> 1 500) (Van Den Eeckhaut and Hervás, in press). However, neither landslide inventories nor landslide susceptibility or risk maps are harmonised among European countries, hampering comparison between different countries and implementation of consistent policies at the European level.

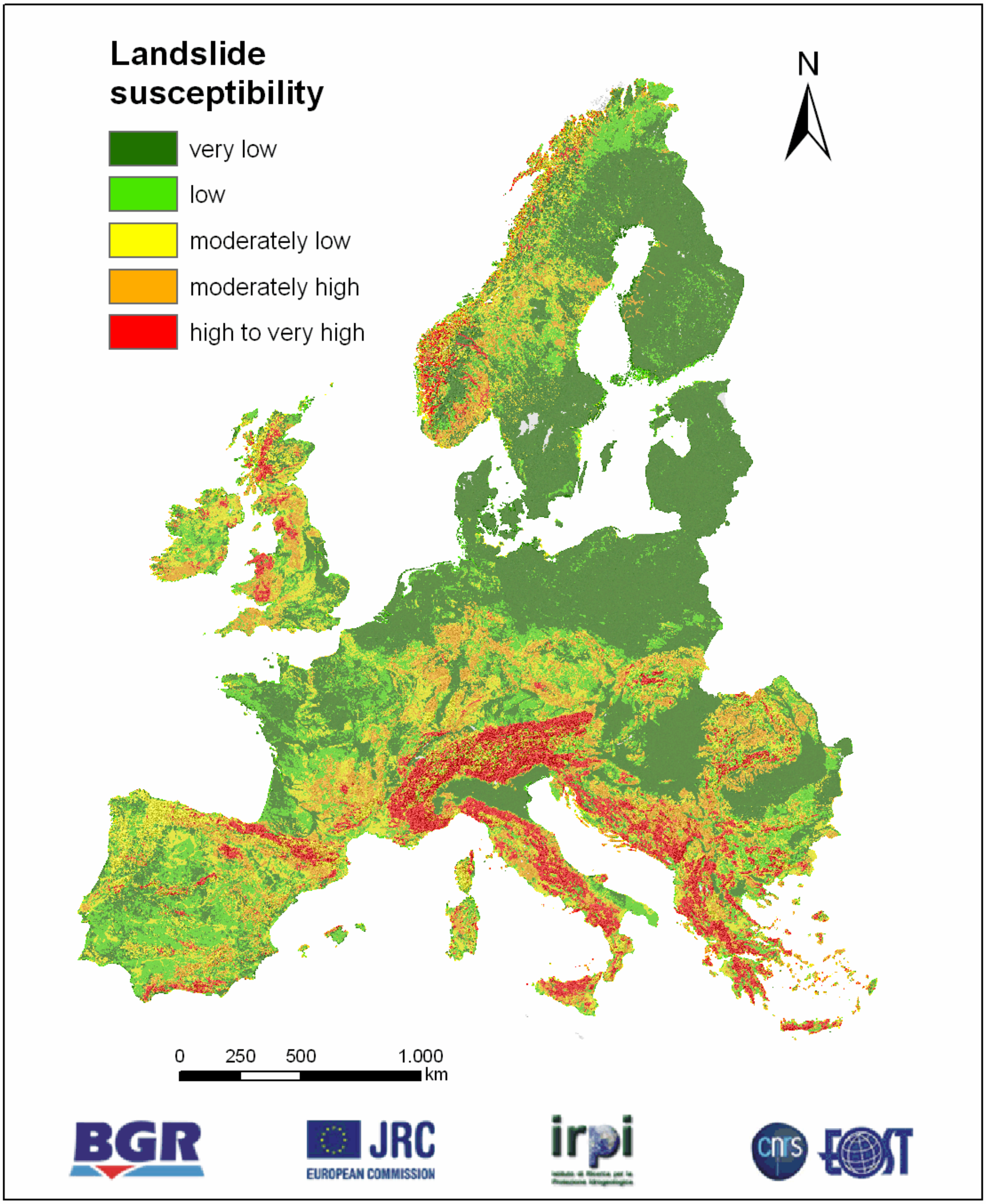

Figure 21: Preliminary map highlighting areas prone to landslides in Europe based on the so-called main conditioning factors of geology, slope, land cover and land use. Factors that can trigger landslides (such rainfall, seismicity, snowmelt volcanic eruptions and human actions) are generally not considered when assessing susceptibility.

Source: Günther et al., in press.

- **Trends in landslides:** While changes in land use, land cover and climate (higher and more intense rainfall patterns) will have an impact on landslides there are no pan-European data on trends in landslide distribution and impact. The national inventories described above will eventually provide the necessary spatio-temporal information to assess trends. Landslides continue to affect people, property and infrastructure.

2.2.10 Soil contamination

It is important to distinguish between local soil contamination (the result of intensive industrial activities or waste disposal Fig. 23; [18]) and diffuse soil contamination covering large areas Fig. 23; [19] (see also the SOER 2010 Assessment on Consumption and the Environment (EEA, 2010d)).

- **State of soil contamination**: It is difficult to quantify the real extent of local soil contamination as many European countries lack comprehensive inventories and there is a lack of EU legislation obliging Member States to identify contaminated sites (the Directive on the management of waste from extractive industries is an exception (EC, 2006a)). Estimates show that the number of sites in Europe where potentially polluting activities are occurring, or have taken place in the past, now stands at about 3 million (EEA, 2007). Some locations, depending on their use and the nature of the contaminant, may only require limited measures to stabilise the dispersion of the pollution or to protect vulnerable organisms from pollution. However, it should be noted that around 250 000 sites may need urgent remediation. The main causes of the contamination are past and present industrial or commercial activities and the disposal and treatment of waste (although these categories vary widely across Europe). The most common contaminants are heavy metals and mineral oil.

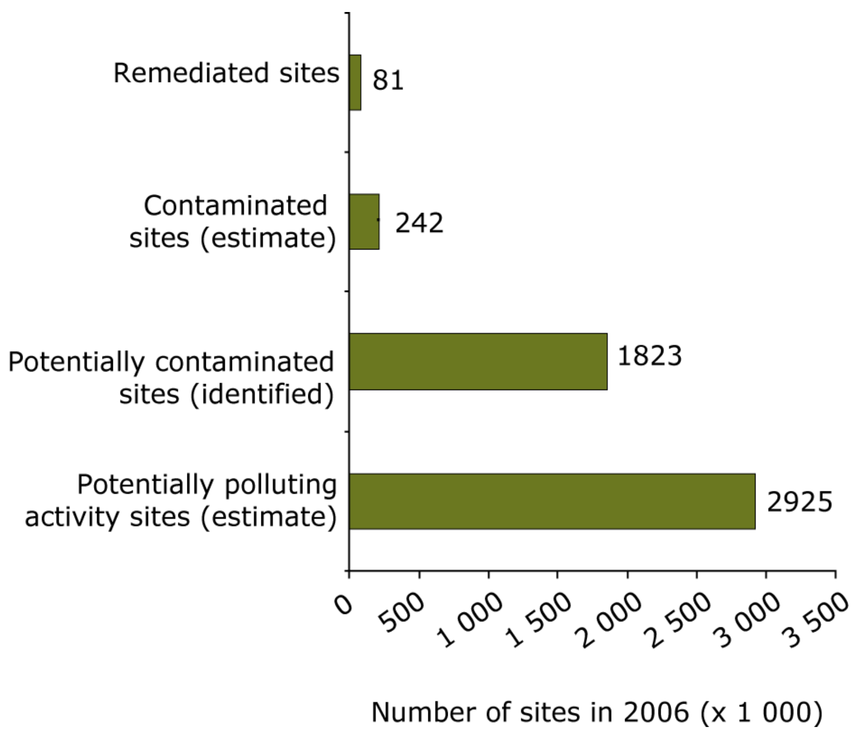

Figure 22: The graph shows the status of identification and clean-up of contaminated sites in Europe as reported to the European Environment Agency through the EIONET priority data flows on contaminated sites. While trends vary across Europe, it is clear that the remediation of contaminated sites is still a significant undertaking.

Source: EEA, 2007.

Data on diffuse contamination across Europe is even more limited than that for local contamination as there are no harmonised requirements to collect information. Rodriguez Lado *et al*. (2008) attempted to map the concentrations of eight heavy metals based on samples from the Forum of European Geological Surveys Geochemical database of 26 European countries, but noted mixed accuracies during the validation phase. Bouraoui *et al*. (2009) modelled fertiliser application rates across EU-25 and showed that approximately 15% of the land surface experienced soil nitrogen surpluses in excess of 40 kg N ha^{-1}. Proxy measurements such as the concentration of nitrates and phosphates in water bodies, including groundwater supplies, can be used as an indication of excessive nutrient application to soils.

- **Trends in soil contamination:** Due to improvements in data collection, the number of recorded polluted sites is expected to grow as investigations continue. If current trends continue and no changes in legislation are made, the numbers reported above are expected to increase by 50% by 2025 (EEA, 2007). There is some evidence of progress in remediation of contaminated sites, although the rate is slow (Figure 22). In recent years, around 80 000 sites have already been treated while many industrial plants have attempted to change their production processes to generate less waste. In addition, most countries now have legislation to control industrial wastes and prevent accidents. In theory, this should limit the introduction of pollutants into the environment. However, recent events such as the flooding of industrial sites in Germany during extreme weather events leading to the dispersal of organic pollutants and the collapse of a dam at the Ajka aluminium plant in Hungary in October 2010 show that soil contamination can still occur from potentially polluting sites. Trends in the deposition of heavy metals from industrial emissions are discussed in the SOER 2010 Assessment on Air Pollution (EEA, 2010c).

A significant factor in diffuse contamination is the over application of agro-chemicals such as pesticides and mineral fertilizers. While reports show that fertiliser sales have remained stable or fallen slightly in EU-15 countries, consumption in Europe as a whole has continued to grow steadily during recent years (FAO, 2008; Eurostat, 2010a). Although it is too early to detect any impact of the current economic crisis on fertiliser applications, a number of recent indicators (e.g. IRENA Gross Nitrogen Balance; EEA 2005a) and reports (EC, 2010a) have noted that nitrate levels in water bodies across Europe have fallen markedly (in 70% of monitored sites between 2004 and 2007). Given that the major source of nitrates in water bodies is runoff from agricultural land, one would expect to observe a similar situation in soil. If biofuel production becomes an important issue in the EU, this could lead to increased fertiliser applications and an increase in areas affected by diffuse contamination. In EU-27, the total area under organic farming increased by 7.4% between 2007 and 2008 and accounted for 4.1% of the total utilised agricultural area (Eurostat, 2010b). Increased use of organic farming methods throughout Europe should result in an improvement of diffuse soil pollution from agro-chemicals. However, good agricultural practices should be adopted to reduce the risk of pollution of water courses from manure applications.

The EU seeks to reduce and level of use of pesticides and their overall impact on health and the environment. In 2006, the European Commission proposed a strategy to improve the way pesticides are used across the EU[7]. The strategy encourages low-input or pesticide-free cultivation, in particular through raising user awareness and promoting the use of codes of good practice. A new legislative framework on the sustainable use of pesticides was adopted in 2009[8] to reduce dependency on plant protection products and consequently lower levels of pesticides in soils.

[7] http://ec.europa.eu/environment/ppps/pdf/com_2006_0372.pdf
[8] http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2009:309:0071:0086:EN:PDF

Figure 23: Examples of soil contamination: Local contamination in the UK resulting from abandoned intensive copper mining and smelting activities (above); diffuse contamination as the result of the application of pesticides on fruit trees in Italy (below).

3 IMPACTS OF SOIL DEGRADATION

Current information suggests that, over recent decades, soil degradation has increased and will increase further if no action is taken. Soil degradation is driven or exacerbated by human activity. Projected climate change, together with individual extreme weather events which are becoming more frequent, is likely to have negative effects on soil.

- **Organic matter decline:** A lowering of soil organic matter (SOM) results in a loss of soil fertility and associated pressures on food production, a decrease in soil strength, reduced water storage (a key element when planning for droughts and flooding), a negative impact on biodiversity, reduced absorption of pollutants with subsequent impacts on water bodies, restrictions on land use and possible loss of land value. Topsoil organic carbon content is also relevant to soil erosion and decline in soil biodiversity.

  Although the quantitative evidence for critical thresholds for organic carbon content is still debatable, it is widely accepted that soil cannot function optimally without adequate levels of organic matter. A threshold of 2% soil organic carbon (SOC) (approximately 3.4% SOM) has been widely used (Kemper and Koch, 1966; Greenland *et al.,* 1975; Huber *et al.,* 2008), but it is clear that a large proportion of intensively cultivated soils of Europe have already fallen below this level (Arrouays *et al.,* 2001; Loveland and Webb, 2003; Verheijen *et al*., 2005; Arrouays *et al.,* 2006; Goidts and Van Wesemael*,* 2007). Recent studies, however, have shown that such thresholds must be considered in the context of actual soil characteristics and geographical location. Verheijen (2005) shows that for sandy soils in relatively dry parts of England, there is no conclusive evidence of significant effects on current soil properties and crop yields when SOC levels are below 2%, although other soil functions are likely to have deteriorated. There are some suggestions that a SOC content of less than 1%, without the addition of organic matter and fertilisers, might result in a disequilibrium in the nitrogen supply to plants, leading to a decrease of both SOC and biomass production (Körschens *et al.,* 1998).

  Land use and land-use change significantly affect soil carbon stocks. On average, soils in Europe are more likely to be accumulating carbon on a net basis (i.e. a sink) in soils under grassland and forest (from 0–100 million tonnes of carbon per year) than under arable land (from 10–40 million tonnes of carbon per year) (Schils *et al*., 2008). Soil carbon losses occur when grasslands, forest lands or native ecosystems are converted to croplands, and carbon stocks increase, albeit much more slowly, when the reverse takes place (Soussana *et al.,* 2004). There is evidence that some soil cultivation methods on arable land can halt the decrease of SOC and even can lead to an increase.

  Declining organic matter contents in soil are also associated with desertification. In addition, there is mounting evidence that greenhouse gas emissions from thawing peatlands could have a significant effect on the global climate (see SOER 2010 Assessment of Global Megatrends, EEA, 2010e).

- **Erosion** can lead to a loss of soil and soil fertility due to disrupted nutrient cycles, restrictions on land use and land value, damage to infrastructure, pollution of water bodies and negative effects on habitat and thus, on biodiversity. Soil erosion by water has substantial off-site as well as on-site effects. The soil removed by runoff, for example during a large storm, will create mudflows and accumulate below the eroded areas, in severe cases blocking roadways or drainage channels and inundating buildings. By removing the most fertile topsoil, erosion reduces soil productivity and, where soils are shallow, may lead to an irreversible loss of the entire soil body. Where soils are deep, loss of topsoil is often not conspicuous but is nevertheless potentially very damaging in the long run.

Estimates from modelling exercises carried out by the JRC show that just over 7% of cultivated land (arable and permanent cropland) in EU-24 (excluding Cyprus, Greece and Malta) suffers from erosion greater than 6 t ha^{-1} yr^{-1} (Bosco *et al*., 2012; Jones *et al*., 2012). A conservative estimate of the consequence of the loss of soil for this area, based on potential loss of wheat yields, reveals that agricultural production in the region of €3.5 billion could be under threat. If the economic loss of soil carbon is also added, the figure would be even higher.

Compaction can detrimentally affect a number of soil functions by reducing the pore space between soil particles, increasing bulk density and reducing or totally destroying the soil's absorptive capacity (Fig. 24a). Reduced infiltration increases surface runoff and leads to more erosion while decreasing groundwater recharge (Fig. 24b).

Heavy loads on the soil surface that cause compaction in the subsoil are cumulative and cause the bulk density of the subsoil to increase significantly. Compaction results in a greatly reduced crop rootability and permeability for water and oxygen. The worst effects of surface compaction can be rectified relatively easily by cultivation, and hence it is perceived to be a less serious problem in the medium to long term. However, subsoil compaction can be extremely difficult and expensive to alleviate and remedial treatments usually need to be repeated. Indeed, once the threshold of the pre-consolidation stress is reached, compaction is virtually irreversible (Ruser *et al*., 2006).

A direct impact of compaction and associated decrease of soil porosity is the reduction in the available habitats for soil organisms. In particular, soil organisms living in surface areas, such as earthworms. Compaction damages earthworm tunnel structures and kills many of them. Alteration of soil aeration and humidity status due to soil compaction can also seriously impact the activity of soil organisms. Oxygen limitation can modify microbial activity, favouring microbes that can withstand anaerobic conditions. This alters the types and distribution of all organisms found in the rest of the soil food web. In addition, both laboratory and field observations have shown that compaction can significantly reduce the numbers of microarthropods involved in biological regulation. The degree of impact varies with both the type of micro-arthropod and soil. Although micro-arthropod populations may recover, this can take several months (Turbé *et al.,* 2010).

Figure 24a: A clear illustration of soil compaction. In this image from The Netherlands, the structure of the uppermost 10cm has been compressed and exhibits a clear horizontal, plate-like form in comparison to the more blocky or angular structure below 10cm © J.J.H. Van Den Akker.

*Figure 24b: A dramatic demonstration of the impact of soil compaction. **T**he soil of an experimental plot (Italy) has been subjected to heavier loads on the right hand side of the image than on the left hand side. The compacted structure of soil on the right has resulted in a reduced infiltration capacity of the soil leading to surface ponding and waterlogging.* © Ezio Rusco;

- **Soil sealing** causes adverse effects on, or complete loss of, soil functions and prevents soil from fulfilling important ecological functions (Fig. 25). Fluxes of gas, water and energy are reduced, affecting, for example, soil biodiversity. The water retention capacity and groundwater recharge of soil are reduced, resulting in several negative impacts such as a higher risk of floods. The reduction in the ability of soil to absorb rainfall, leading to rapid flow of water from sealed surfaces to river channels, results in damaging flood peaks. Above-ground biodiversity is affected through fragmentation of habitats and the disruption of ecological corridors. These indirect impacts affect areas much larger than the sealed areas themselves. Built-up land is lost for other uses such as agriculture and forestry, as sealed soils are often fertile and high value soils and in close proximity to existing urban areas (Fig. 26). Soil sealing appears to be almost irreversible and may result in an unnecessary loss of good quality soil. Sealing can lead to the contamination of soil and groundwater due to the collection of unfiltered runoff water from urban and industrial sites. This is exacerbated during major flood events and was clearly demonstrated by the 2002 floods on the Elbe which deposited levels of dioxins, PCBs and mercury from industrial storage areas to the soils of floodplains, in excess of national health thresholds (Umlauf *et al.,* 2005).

  Soil sealing can affect the natural temperature regulation in urban areas. Unsealed areas are cooler than sealed zones. Considering that the mean temperature in Europe and the number of heat waves is expected to increase, a high level of soil sealing will further exacerbate the already existent heat island effect of cities and increase their vulnerability to heat wave impacts (EEA, 2010a,b).

Figure 25: Soil sealed by road construction. © Otto Spaargaren

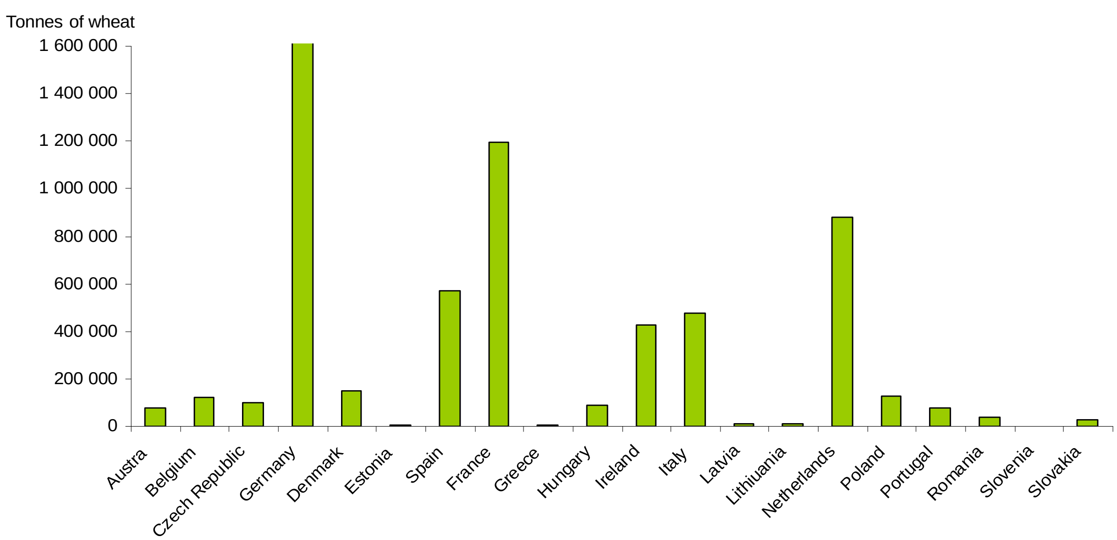

Figure 26: Annual impact of soil losses due to urbanisation during the period 1990-2006. The annual impact of soil losses, due to urbanisation, on the production capability of agriculture in the EU-25 has been estimated to be equivalent to the loss of more than 6 million of tonnes of wheat.

Source: JRC/Gardi et al., 20011.

- **Salinisation:** Elevated salt levels in the soil limit its agro-ecological potential and represent a considerable ecological and socio-economic threat to sustainable development. Salts can cause harm to plant life (reduced soil fertility, agricultural productivity and biomass yield); natural vegetation (ecosystems); life and function of soil biota (biodiversity); soil functions (increased erosion potential, desertification, soil structure and aggregate failure, compaction and clay dispersion); the hydrological cycle (moisture regime, increasing hazard, frequency, duration and severity of extreme moisture events such as floods, water-logging, and drought); and bio-geochemical cycles (availability of plant nutrients, reduced soil organic matter levels).

- **Acidification:** Anthropogenic pollutant deposition enhances the rates of acidification, which may then exceed the natural capacity of soils to neutralise acids (van Breemen *et al.,* 1983). Acidification affects all aspects of the natural environment: soils, waters, flora and fauna. Very acidic soil can reduce crop productivity by up to 50% through the loss of organic material, nutrient deficits, aluminium toxicity, and increased solubility of metallic trace elements. Indirectly, the reduction of plant cover could lead to increased erosion (SAEPA, 2008). Acidification leads to substantial damage of watercourses and lakes through the lowering of pH and increased aluminium concentrations which can affect aquatic life, groundwater and the related drinking water supply. Acidification depletes the buffering capacity of the soils and thus changes its ability to neutralise acidity. In a similar manner, soil biology can also be seriously damaged by acidification as certain biota are unable to adapt to changes in soil chemistry. Liming of soils can offset the effect of acidification, but in some circumstances it can have undesirable effects on soil biota and flora through the elimination of certain species.

- **Desertification** is a threat to some of the poorest and most vulnerable parts of Mediterranean Europe (Zdruli *et al.,* 2007). Water scarcity limits several ecosystems services normally provided by soil. A decline of soil biota and organic matter accumulations can lead to a collapse in soil fertility and the associated production of biomass. Under such conditions, the agricultural system, which supports the local population, will fail. Increasing aridity may limit the ability of an ecosystem to recover from a number of specific pressures (e.g. drought, fire, population growth). This in turn will lead to an increase in desertification. Droughts are often broken by intense storms that can wash away large amounts of soil, which has been made more vulnerable by the lack of vegetation cover or crusting, leading to low infiltration rates. The loss of soil fertility and subsequent failure of vegetation can increase susceptibility to wind erosion and the formation of dust clouds that can cause health problems in distant areas. Desertification also implies the 'culmination' or a final outcome of dryland degradation, unless immense resources are invested to reverse it.

  Recent European droughts, for example in 2003 and 2008, have highlighted the impact of desertification and shown its significant effect on European economies. Rubio and Recatala (2006) estimate that desertification affects 30% of semiarid Mediterranean drylands, 65% of European drylands, and 10% of Europe. Correia (1999) estimates also that 27% of the population of the European Mediterranean is affected by severe land degradation.

- **Soil biodiversity:** Pressures such as climate change, land-use change, habitat disruption, soil organic matter decline and erosion can lead to a reduction in the number of soil organisms and a loss of biological diversity. This can in turn result in changes of ecosystem functions and loss of ecosystem goods and services. Soil degradation processes can affect soil biota and biodiversity levels at various scales. At the farm level, changes can occur in the productive capacity of the system via a reduction in the mineralisation of nutrients from organic resources and nitrogen fixation. At the regional/national level, there can be short-term and long-term changes of food security resilience. At the global level, bio-geochemical cycles (organic matter mineralisation, nitrogen fixation, etc.) can be disrupted. Inventories and monitoring are needed to achieve an adequate level of knowledge on soil biodiversity status, the location of hot spots and the areas subject to decline. Recent analysis (Fig. 27) has indicated that due to land use change, habitat disruption, invasive species, soil compaction, erosion, pollution and organic matter decline, soil biodiversity levels are potentially under high pressure in approximately 23% of the surface area of EU-25 (excluding Sweden and Finland) and under very high pressure in 8% of this area (Jeffery *et al*., 2010).

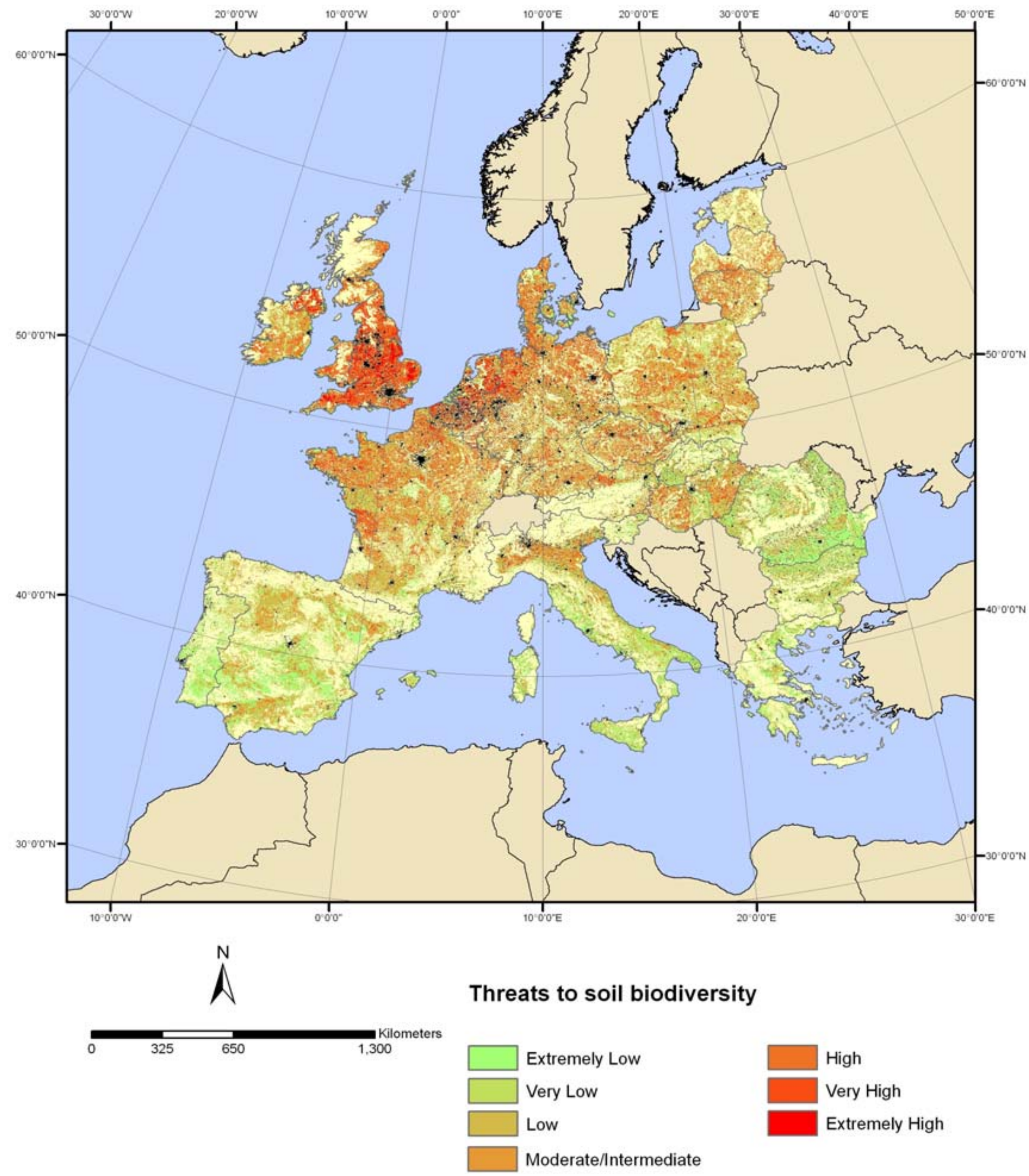

Figure 27: Potential threats to soil biodiversity on the basis of expert evaluation, taking into account factors such as land use change, intensive management and soil degradation processes such as compaction, pollution and erosion. The main driver for the high values is intensive agriculture.

Source: JRC/Jeffery et al., 2010

- **Landslides:** Landslides can cause the deterioration or even total loss of one or more soil functions. Shallow landslides may remove valuable topsoil which severely restricts how the land can be used. Landslide debris can also cover the soil downslope from the area where the slope has 'failed' thus burying the existing soil. In severe cases, when the entire soil body is removed from its in situ position, all soil functions will be lost.

  Landslides are a major hazard in most mountainous and hilly regions as well as in steep river banks and coastlines. Their impact depends mainly on their size and speed, the elements at risk in their path and the vulnerability of these elements. Every year landslides cause fatalities and result in significant damage to infrastructure (roads, railways, pipelines, artificial reservoirs, etc.) and property (buildings, agricultural land, etc.). Large landslides in mountain areas can result in the blockage of river courses. Such natural dams cause inundations upstream and can subsequently be breached by lake water pressure, generating deadly flash floods or debris flows downstream. Large coastal cliff landslides, together with landslides into lakes and reservoirs, can trigger tsunami events. Landslides can also affect mine waste tips and tailings dams and landfills, causing fatalities and contaminating soils, and surface- and ground water. The impact of landslides in built-up areas can be significantly reduced by adequate non-structural measures, including integrating landslide susceptibility/hazard and risk mapping in land-use planning activities and establishing early warning systems for active landslides (Hervás, 2003).

  A positive impact of landslides is that they are a major source of sediment for valleys and rivers. At the same time, landslides can decrease water quality by increasing water turbidity and saturation in some elements.

- **Contamination:** Soil contamination can have lasting environmental and socio-economic consequences and be extremely difficult and costly to remediate. Contamination can seriously affect the ability of soil to perform some of its key ecosystem functions. Thresholds for most pollutants exist in most countries but these can vary and often do not consider the multifunctional usage of soil (Huber *et al.,* 2008). In extreme situations where contaminant levels exceed a critical threshold, the soil body may be considered as 'functionally dead'. Pollution by heavy metals and organic contaminants is probably the most serious problem as the contamination is practically irreversible. Contamination can affect human health either through direct contact or by ingestion through the food chain.

  Diffuse contamination by nutrients, fertiliser impurities (e.g. cadmium) and biocides is more concentrated in areas with intensive agricultural production and can have significant impacts on soil biology communities (and thus soil functions), groundwater sources, and crop uptake. Industrial emissions of persistent organic compounds such as PCBs and dioxins to agricultural soil and their subsequent introduction into the food chain can lead to the development of tumours in people.

- **Human health and soil:** Poor soil quality can affect human health in several ways, leading to specific diseases or general illness. Pathogens (such as tetanus), parasites (e.g. hookworm) and concentrations of toxic elements (e.g. aluminium, arsenic, cadmium, copper) in the soil can lead to a decline in general health (UKEA, 2009). The concentrations might reflect the natural condition of the soil or the consequences of pollution, particularly resulting from industrial processes. Wind-blown dust can cause problems for people with asthma and other respiratory conditions. Many of the relationships between soil and health are unclear and require further research.

- **Costs of soil degradation:** Although difficult to estimate accurately, soil degradation has economic consequences for the environment and society. The costs of degradation depend on the process, its spatial extent and intensity, the natural characteristics of the location and the socio-economic characteristics of the surrounding area. However, while such factors have been addressed in local case studies, the calculation of a Europe-wide figure is impeded by the fact that much of the data is either unavailable or not comparable. The Impact Assessment document of the Soil Thematic Strategy (EC, 2006b)[9] estimates the following costs of soil degradation:

    - organic matter decline: EUR 3.4–5.6 billion/year
    - erosion: EUR 0.7–14.0 billion/year
    - compaction: no estimate available
    - sealing: no estimate available
    - salinisation: EUR 158–321 million/year
    - biodiversity decline: the global economic benefits of soil biodiversity are estimated at around EUR 2 billion/year. No figures are available for Europe
    - desertification: at least EUR 3.3 billion/year
    - landslides: according to the Italian Civil Protection Department, landslides cost the Italian economy between EUR 1–2 billion per year. Other estimates range from EUR 11–600 million per event (EC, 2006b)
    - contamination: EUR 2.4–17.3 billion/year (based on single case study in France).

  No assessments of the costs of compaction, soil sealing or biodiversity decline are currently available. The total costs of soil degradation in the form of erosion, organic matter decline, salinisation, landslides and contamination could be up to EUR 38 billion annually for the EU-25. These estimates are necessarily wide-ranging due to the lack of sufficient quantitative and qualitative data.

  Evidence shows that the majority of the costs are borne by society in the form of damage to infrastructures due to sediment runoff and landslides, increased healthcare needs for people affected by contamination, treatment of water contaminated through the soil, disposal of sediments, depreciation of land around contaminated sites, increased food safety controls, and costs related to the ecosystem functions of soil.

[9] http://ec.europa.eu/environment/soil/three_en.htm.

4 OUTLOOK 2020

The inherent complexity and spatial variability of soil makes the evaluation of the impact of any change difficult. Transformations of features such as texture and mineralogical composition will only occur over geological time spans while properties such as pH, organic matter content or microbial activity will show a more rapid reaction. In addition, the response of a particular soil type may be both positive and negative depending on the function in question. For example, rising temperatures and precipitation may support increased agricultural productivity on soils previously deemed marginal, but such a transformation can lead to a deterioration of soil biological diversity and an increased risk of erosion. Quantitative assessments of future trends in soil characteristics and properties are limited. As a consequence, this chapter provides an outlook only for a selected number of issues. Considerably more effort is required to model changes in the state of soil conditions in relation to drivers such as changes in land use and climate. Further discussions on the outlook on urban development and possible impacts on soil sealing can be found in the SOER 2010 Land Use Assessment (EEA, 2010b).

4.1 Soil organic matter, carbon and the global climate

Variations in soil organic matter (SOM) will have a marked effect on fertility, biodiversity, soil structure, water retention capacity, risk of erosion and compaction. By absorbing many times its weight in water (estimates range from 3% to 20%; Reicosky, 2005; JRC 2009) increased SOM could contribute to the mitigation of flooding following extreme rainfall events while storing water in the event of more frequent and severe droughts. Two issues dominate the outlook for SOM: climate change and land use change.

As a carbon sink, soil can sequester CO_2 from the atmosphere thus mitigating global warming. In areas with low temperatures and sufficient moisture, the decomposition of dead biomass — leaves, stems, roots of plants — is reduced giving rise to accumulations of soil organic carbon (SOC). Increasing temperatures will accelerate decay rates, leading to an intensification of CO_2 and CH_4 emissions from the soil to the atmosphere. Soils in the EU contain around 75 billion tonnes of carbon or 7% of the total global carbon budget (IPCC, 2000a). This is a huge amount compared with the 2 billion tonnes of carbon emitted annually by EU Member States. Releasing just a fraction of the carbon in European soils to the atmosphere could easily wipe out any savings of anthropogenic greenhouse gas emissions made by other sectors (Schulze *et al*., 2009).

IPCC climate change scenarios [20] up to 2020 show generally warmer temperatures for the whole of Europe with northern Europe experiencing increased precipitation and warmer winters. Scenarios for southern Europe show warmer but drier conditions. As shown previously, climate, land use and land use change are the key drivers of SOM levels. All other factors being equal, it is apparent that changing climate will have variable consequences on SOC in different parts of Europe. Warmer and wetter conditions, as long as the soils are not saturated, will lead to increased soil respiration and a lowering of current levels of SOC. Drier conditions could lead to vegetation stress and less organic matter input to the soil. Given the already low values of SOC in southern Europe, any further reduction of SOC levels would trigger an increased risk of erosion in vulnerable soils and support the northward expansion of desertification (Fig 28). Changes in vegetation characteristics will also play an important role (e.g. northward shift of boreal forest).

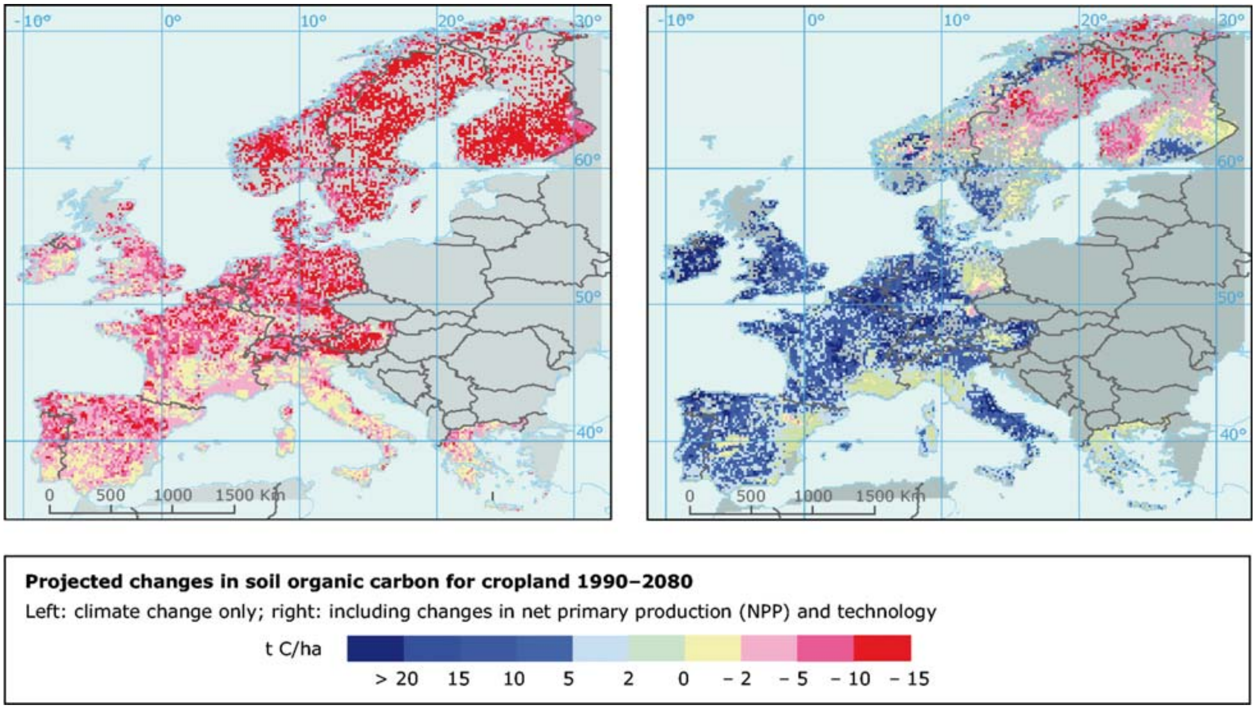

Figure 28: Predicted changes in soil organic carbon for croplands 1990–2080. The image on the left shows changes due to climate change only, while the map on the right shows changes as a result of variations in net primary production and the advent of new technologies related to crop management (e.g. machinery, pesticides, herbicides, agronomic knowledge of farmers) and breeding (e.g. improved stress resistance) that result in yield increases. The changes for other land cover types (grasslands, forests, heaths) will be different to those shown above.

Source: Smith et al., 2005.

Conversely, the warmer and more humid conditions in Fennoscandinavia could lead to more vegetation growth, higher levels of soil biodiversity and an enhancement of SOC stocks. Figure 29 illustrates how local conditions and climate will determine the carbon fluxes for peatlands.

It is worth noting that while climate is a key soil forming factor and governs a large number of pedogenic processes, soil can also influence global climate. Soils in the northern latitudes store huge amounts of organic carbon, much of which is affected by permafrost and permanently or seasonally frozen. Currently, around 500 Gt of carbon is stored in permafrost-affected soil in the northern circumpolar region (Tarnocai *et al.,* 2009). Large releases of greenhouse gases from these could have a dramatic effect on global climate, although the exact relation is complex and requires additional research. As these processes are of significant concern, appropriate wetland management and land-use practices should be developed in the EU to maintain or enhance soil carbon stocks and further research and monitoring is needed to assess changes in permafrost-affected soils.

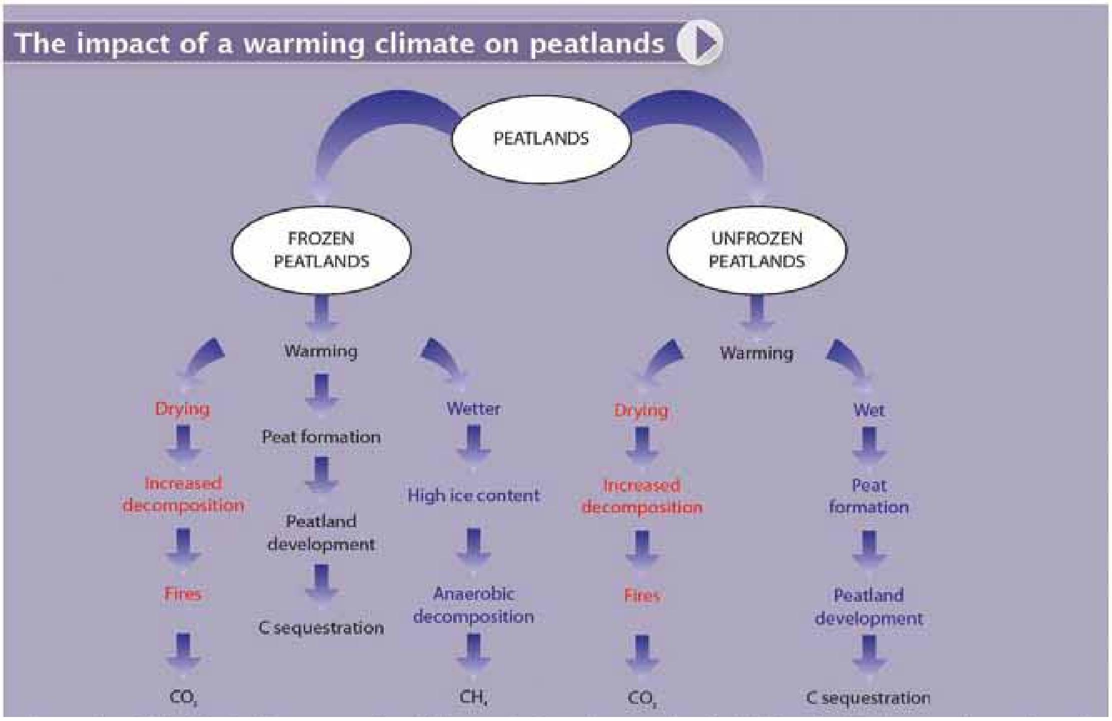

Figure 29: The above figure illustrates how the impact of a warming climate on peatlands depends on their initial frozen or unfrozen status. Warmer conditions would result in increased peat formation as long as ground conditions were wet enough to reduce decomposition. The wet soil conditions after the permafrost has thawed will result in an increase in methane (CH_4) emissions. This is unforeseen from unfrozen peatlands. Warmer and drier conditions will give rise to carbon dioxide (CO_2) emission from both frozen and unfrozen peatlands associated with the increased decomposition rates. This example shows that the processes and climate warming projected on different types of soil will initiate a variety of soil evolutions and environmental consequences.

Source: Jones et al., 2010.

The second key driver that affects SOM is land use. Several studies have evaluated rural development and agricultural scenarios to 2020 — all of which have an impact on SOM. The SCENAR 2020 report (EC, 2006c) noted that the relative importance of various agricultural commodities increasingly depends on world markets and concludes that beef and dairy herds are most likely to decrease. These conditions will have an impact of land area devoted to fodder crops and to extensive grazing, with a possibly significant regional impact in terms of land being taken out of agriculture altogether. In the period from 2000 to 2020, arable land is expected to decrease by 5%, grassland by 1%, and permanent crops by 1%. Forest is projected to increase in land cover by 1%, other natural vegetation by 2%, recently abandoned land by 3% and urban land by 1%. It is clear that such changes would have a significant impact on SOM.

The report 'Soil organic matter management across the EU – best practices, constraints and trade offs' (Gobin *et al.*, 2011)[10] quantifies the effect on soil organic matter or on the precursor to soil organic matter (i.e. humified organic carbon) of selected environmental policy and resource management options to the 2030 time horizon. These included abolishing restrictions as to maintaining grasslands in cross compliance and exporting increasing amounts of crop or forestry residues out of fields or forests. Abolishing permanent grassland restrictions would have a negative effect on soil organic carbon stocks, which at EU level can be quantified in a carbon stock loss 30% higher than in the case of maintaining

[10] http://ec.europa.eu/environment/soil/som_en.htm.

the current permanent grassland restrictions. Exporting 30% or 50% of cereal residues results in a decrease of humified organic carbon of 7% or 21% respectively, reaching minus 38% in a worst case scenario in which all residues are exported out of the field. When 70% of the wood residues and 25% of the stumps are removed from a forest, there is a decrease of humified organic carbon of 35.6% for coniferous forests and 33.6% for broadleaved forests.

4.2 Erosion

There is now widespread acceptance that inappropriate land management practices and changes in land use, such as the felling of woodland or the conversion of grasslands to arable agriculture, can lead to increased erosion rates. Consequently, it is obvious that changes in land management practices will have a major bearing on future erosion patterns across Europe. The reform of the EU Common Agricultural Policy (CAP) has to consider the environmental consequences of agricultural practices. Instruments under rural development policies could help mitigate the effects of land abandonment, especially in southern Europe where land management practices, such as the maintenance of terrace systems, could play a major role in combating soil erosion (see Chapter 5).

It is clear that climate change could influence soil erosion processes and, in many ways, the outlook for 2020 reflects the earlier discussions on soil organic matter (4.1). IPCC scenarios show increased extreme weather events giving rise to intense or prolonged precipitation. Sheetwash, rill and gully development can strip the topsoil from the land, thus effectively destroying the ability of the soil to provide economic and environmental services. Favis-Mortlock and Boardman (1995) found that a 7% increase in precipitation could lead to a 26% increase in erosion in the United Kingdom.

Increasing air temperatures will also affect soil erosion in several ways. Increased summer drought risk in central and southern Europe can cause severe damage to soil. Aridity influences soil structure and hence increases erosivity. Higher temperatures can increase biomass production rates but at the same time limit vegetation cover because of excessive heat and increasing dryness (Pruski and Nearing, 2002).

Many of the soil erosion risk models contain a rainfall-erosivity factor and a soil-erodibility factor that reflect average-year precipitation conditions. However, currently available values for the rainfall-erosivity and soil-erodibility factors may inadequately represent low-probability return-period storms, and the more frequent and intense storms projected under climate change are not considered. Several studies have been conducted to model the effects of climate change on soil erosion. Kirkby *et al*. (2004) describes a non-linear spatial and temporal response to climate change, with relatively large increases in erosion during wet years compared to dry years, and sporadic increases locally. Nearing *et al*. (2005) showed that erosion increases with increases in precipitation amount and intensity, while erosion decreases with increases in ground and canopy cover. These results are consistent with the expectation that erosion should increase as the main driving force — rainfall — increases. For Fennoscandinavia, warmer winter temperatures will result in less snow cover and an increase in the number of snowmelt episodes. Both conditions will result in an increased risk of erosion.

4.3 Water retention

Water retention is a major hydraulic property of soils that governs soil functioning in ecosystems and greatly affects soil management, especially in times of droughts or floods. Soil water retention characteristics depend largely on texture, the amount of SOM and climate. Variations in any of these three variables will affect soil water retention characteristics and ultimately, soil functions (e.g. for agriculture, water storage).

While variations in SOM levels to 2020 have been described in Section 4.1, it is clear that changes in SOM levels will influence water retention capacity. Given the strong direct relationship between soil water capacity and organic carbon, any intensification of mineralisation processes will detrimentally affect the water retention capacity of soil and hence its usability. Rawls *et al*. (2003) showed that at low SOM levels, any increase in SOM only leads to an increase in water retention in coarse soils while at high SOM levels, any increase in SOM results in an increase in water retention for all textures. This implies that the pattern of change in water retention due to climate change pressures on SOM could vary locally according to soil type, organic matter content and even the nature of the organic matter.

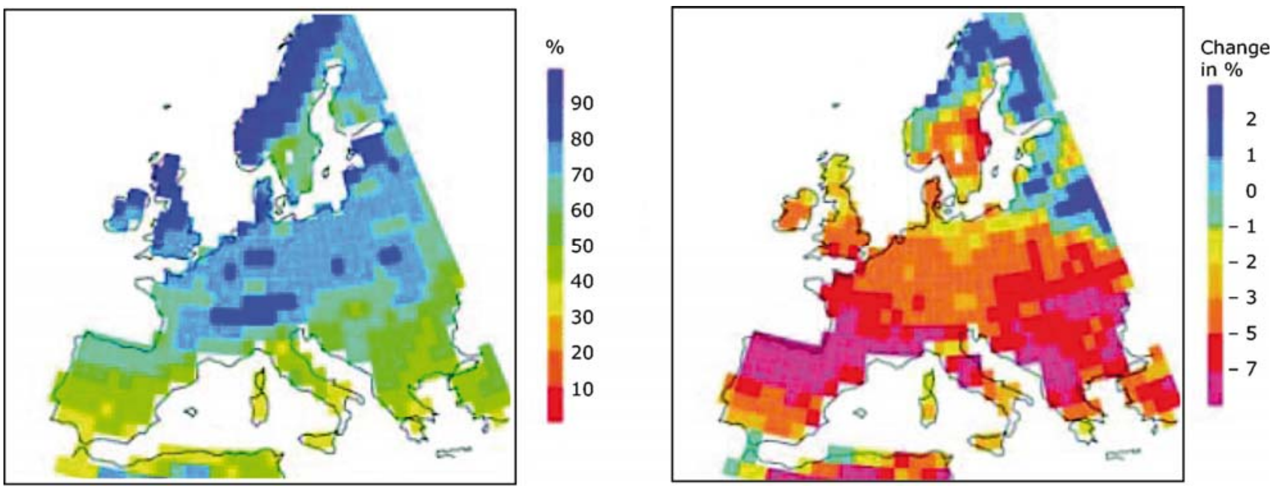

Figure 30: Summer soil moisture conditions over Europe for the period 1961–1990 (left) and projected changes for 2070–2080 (right). While this time frame is beyond the reference period of this chapter, the scenario described on the right would clearly have a significant impact on soil levels over most of the European Union.

Source: Simulated by the ECHAM5 global climate model. Calanca et al., 2006.

Increased temperatures and decreasing precipitation across Europe will result in changes in evapotranspiration (the sum of evaporation from the Earth's land surface and transpiration, the loss of water from plants to the atmosphere) and soil moisture levels (Fig. 30). Models indicate that the impact of global warming on evapotranspiration shows a sharp transition from slight increases (0.1–0.5 mm/day) in the north of Europe to reductions (of the order of − 0.5 mm/day) in Mediterranean areas (Calanca *et al*., 2006). For all of central and northern Europe where soil moisture levels exceed 75% of the field capacity (the amount of water held in soil after excess water has drained away), evapotranspiration increases by about 0.3 mm/day.

Unless suitable land management procedures are implemented, increased and more severe droughts will cause soil water retention mechanisms to collapse, leading to the onset of erosion, desertification and increased risk of flooding.

4.4 Acidification

Regulatory controls initiated in recent decades have had a significant impact on the emissions of pollutants that cause acidification, mainly as a result of decreased SO_2 emissions. By 2020, it is expected that the risk of ecosystem acidification will only be an issue at some hot spots, in particular at the border area between the Netherlands and Germany (EEA, 2010h). Recovery from acid deposition is characterised by decreased concentrations of sulphate, nitrate and aluminium in soils. An increase in pH and acid-neutralising capacity (ANC), coupled with higher concentrations of base cations, would, in turn, improve the potential for biological recovery. However, given the delay in the response of soil to decreases in acid deposition, it is reasonable to suggest that many decades will be required for affected sites to recover fully. Additional information on trends in acidification is presented in the SOER 2010 Air Pollution Assessment (EEA, 2010c).

4.5 Biofuels

There is considerable interest in the possible impact of increased biofuel production on soil quality and soil functions. The conversion of sugars from bioenergy crops into fuel or biomass to liquid fuels such as ethanol and biodiesel or gaseous fuels such as methane are increasingly being regarded as sustainable alternatives to fossil fuels. Biofuel production involves the cultivation of suitable crops. There are concerns that increasing biofuel production may lead to inappropriate land management practices and increased levels of soil degradation. A study by the European Commission in 2007 on the impact of a minimum target of 10% biofuel in total transport fuel use by 2020 noted that the total land used for first and second generation biofuel production in EU-27 would be 17.5 million ha by 2020. This area would be derived from existing agricultural land and land that had been mandatorily set aside, to which severely degraded and contaminated land could be added (EC, 2007). Organic matter depletion and loss of essential plant nutrients from soils lead to the need for increased inputs (such as fertiliser) which, over time, could lead to a loss of soil quality and associated functions. On a global level, a high biofuel demand may result in competition between biofuel and food production (UNEP, 2009). As already mentioned, the study by Gobin *et al.* (2011)[11] shows that exporting 30% or 50% of cereal residues results in a decrease of humified organic carbon of 7% or 21% respectively, reaching minus 38% in a worst case scenario in which all residues are exported out of the field. When 70% of the wood residues and 25% of the stumps are removed from a forest, there is a decrease of humified organic carbon of 35.6% for coniferous forests and 33.6% for broadleaved forests.

During 2009 and 2010, the European Commission worked intensively to give a better understanding of Indirect Land Use Change (ILUC) effects from increased use of biofuel. ILUC occurs when the production of crops for biofuel in a given land pushes the previous activity to another location. The use of the new location to place the previous activity generates a land-use change attributable to the introduction of the biofuel crop. In other words, if the biofuel crops are grown on previously uncultivated land, this will cause direct land use change. If arable land is used to produce biofuel instead of food, this will likely cause ILUC because of the need to produce the food elsewhere. Due to related changes in the carbon stock of the soil and the biomass, indirect land-use change has consequences in the greenhouse gas (GHG) balance of a biofuel.

To assess the impact of land use changes due to biofuel production, the JRC has developed guidelines to quantify changes in the amount of organic carbon in soils and biomass (Carré *et al.,* 2010; Hiederer *et al.,* 2010). This is an important factor in the sustainability assessment. The guidelines follow the Intergovernmental Panel on Climate Change (IPCC) guidelines for national greenhouse gas inventories and are supported by comprehensive global data processed by the JRC (Fig. 31). The guidelines formed the basis for the Commission decision on the guidelines for the calculation of land carbon stocks[12]. Based on the guidelines a method was developed to estimate greenhouse gas (GHG) emissions from

[11] http://ec.europa.eu/environment/soil/som_en.htm.
[12] http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2010:151:0019:0041:EN:PDF

land use changes due to biofuel production.

The method follows a two-step approach:

- Creation of a dedicated database (e.g. land use/crop cover/soil types etc.), which includes combining data from different sources and newly processed data into a harmonized database;
- Simulation based on cropland demands from the general equilibrium model MIRAGE (run by the International Food Policy Research Institute (IFPRI)) and on cropland demand from the partial equilibrium model AGLINK-COSIMO (run by JRC-IPTS).

The new system, adopted in June 2010 by the European Commission, encourages industry, governments and NGOs to set up voluntary certification schemes for all types of biofuel (EC, 2010b). It will help to ensure that all biofuel (including those imported into the EU) are sustainable and deliver high greenhouse gas (GHG) savings, at least 35% when compared to fossil fuels. This excludes specific land categories, such as primary forests, wetlands, peatlands and areas with high biodiversity.

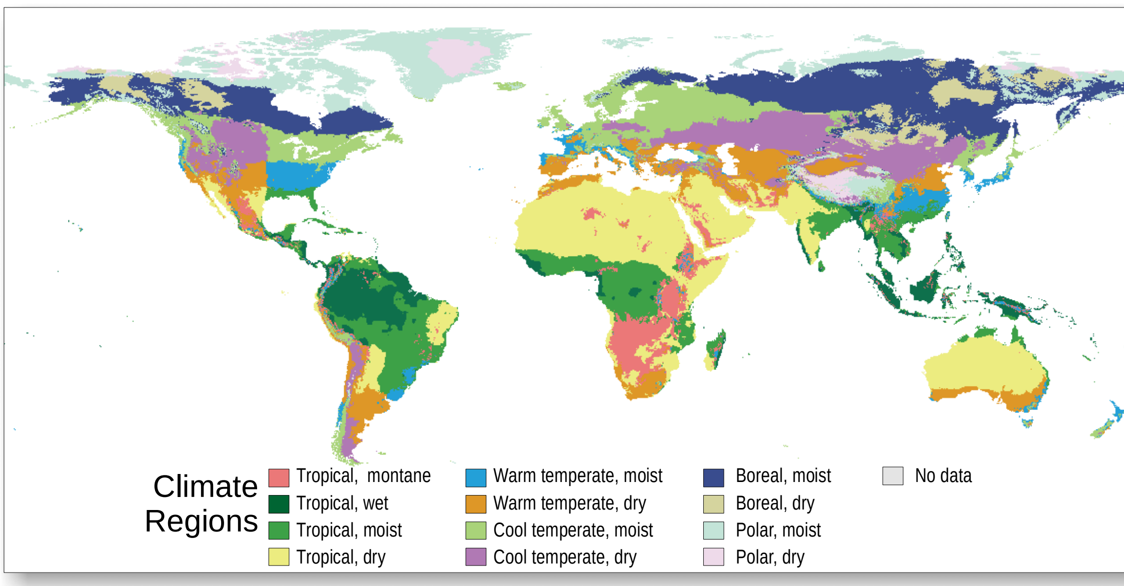

Figure 31: A global climate regions database has been developed by the JRC, on the basis of an IPCC classification, to develop guidelines for the calculation of land carbon stocks.

Source: JRC/Hiederer et al., 2010

5 RESPONSE

5.1 A pan-European approach to increased soil protection

After a thorough development process involving a broad range of stakeholders, the European Commission adopted a Soil Thematic Strategy on 22 September 2006 (EC, 2006d)[13]. The strategy tackles the full range of threats and creates a common framework to protect soil. Its objective is to halt and reverse the process of soil degradation, ensuring that EU soils stay healthy for future generations and remain capable of supporting the ecosystems on which our economic activities and our well-being depend.

The strategy explains why EU action is needed to ensure a high level of soil protection and what kind of measures must be taken. The objective is to define a common and comprehensive approach to soil protection, focusing on the preservation of soil functions. An integral part of the strategy is the proposal for a Soil Framework Directive (EC, 2006e) [21], which is structured along three lines: 1) **Preventive measures**: Member States must ensure a sustainable use of soil. If soil is used in a way that hampers its functions, mitigating actions must be undertaken. Other policies' impacts on soil must be assessed; 2) **Identification of the problem**: Member States must identify the areas where there is a risk of erosion, decline in organic matter, salinisation, acidification, compaction, or landslides. As far as contamination is concerned, Member States must draw up an inventory of contaminated sites; 3) **Operational measures**: Member States will then have to act upon the risks identified by adopting programmes of measures for the risk areas, national remediation strategies for the contaminated sites, and measures to limit or mitigate sealing. However, Member States have a large scope to set targets and to decide how and by when to achieve them.

As shown in Chapter 2, soil degradation in the EU is continuing to occur and is actually worsening in some parts of Europe. This is a clear demonstration that existing policies and legislation, at EU as much as at national or regional level, have not been sufficient. Action is required at EU level, because of the crucial functions soil performs for society European ecosystems, the transboundary effects of some soil degradation processes and because of legislative differences between Member States in dealing (or not dealing) with soil problems that may distort competition within the single market and prevent the Union from meeting international targets (e.g. in climate and biodiversity conventions). In addition, soil quality is strongly related to other environmental aspects of EU relevance (e.g. air, water, biodiversity, the carbon cycle). An effective policy for the future cannot neglect to take care of soil because of its links to other environmental goals (e.g. the Water Framework Directive).

The proposal for the Directive received the backing of the European Parliament in November 2007, but so far the Environment Ministers have not been able to reach a qualified majority in its favour. Despite a majority of Member States supporting the proposal, a number of countries argue that soil degradation does not have transboundary consequences and thus soil legislation should be a matter of national competence only (the principle of subsidiarity). Other concerns include the private ownership of soil, the administrative burden, technical arguments regarding the delineation of susceptible areas and costs of making inventories. However, soil degradation does have transboundary consequences (e.g. eroded sediments, loss of soil carbon, spreading of contamination across borders) and any 'wait-and-see' policy would lead to more soil degradation across the EU. Some countries are already adopting aspects of the EU Soil Thematic Strategy into their national legislation.

In the context of the Soil Thematic Strategy, European policy makers require access to European soil data and information of various types to assess the state of soils at European level. As part of this need

[13] http://ec.europa.eu/environment/soil/index_en.htm

to collect and assess soil data and information, the European Commission and the European Environment Agency decided to establish a European Soil Data Centre (ESDAC), located at the EC's Joint Research Centre, as one of ten environmental data centres in Europe. ESDAC acts as the primary data contact point for the EEA and the Commission to fulfil their soil information needs. The establishment of harmonised databases would enable a better identification of degraded soils across Europe, identify areas where data are lacking while assessing the effectiveness of soil protection measures.

5.2 The role of the CAP in promoting sound soil/land management practices

Agriculture occupies a substantial proportion of European land, and consequently plays an important role in maintaining soil resources. At present, the impacts of changes to the Common Agricultural Policy (CAP) on overall soil quality are difficult to assess accurately. Specifically on the issue of SOM levels, the CAP appears to have effectively maintained the status quo in many grassland areas. The cross-compliance requirement to sustain levels of permanent pasture (within certain margins) could help maintain soil structure and organic matter levels in soil, and so soil carbon. In contrast, the abolition of 'set-aside' land[14] could lead to negative impacts on soils as the loosening of regulations to allow land to go back into production under tillage crops could lead to a reduction in soil carbon stocks and an increase in emissions of CO_2.

The CAP is able to encourage a number of farming practices that maintain soil fertility and organic matter levels by improving the physical characteristics of soil and its capacity to retain water (e.g. agri-environmental measures, organic farming, increasing soil nutrient levels through natural fixation by plants and crop rotation). For example, conservation agriculture, a combination of no-tillage or reduced tillage, cover crops and crop rotation, is generally reported to have reduced impacts on the composition and structure of the soil, reducing the risk of erosion and degradation, and loss of soil biodiversity. This includes, for example, no-tillage, reduced tillage, cover crops and crop rotation. Current good agricultural and environmental condition (GAEC) standards for soil protection may be useful for improving the long-term relationship between agriculture and soil. However, soil sealing, contamination, salinisation and shallow landslides are not subject to specific standards, although measures adopted for maintaining good agricultural conditions, for example, soil structure, can in principle be considered to contribute to the prevention of landslides. In addition, GAEC standards apply to land subject to direct payments, not to all agricultural land. For the future of the CAP, the removal or reduction of production-related agricultural subsidies and increased support for agri-environmental measures may have beneficial impacts by increasing the potential for carbon sequestration, by allowing for the reversion of some agricultural land into more natural eco-systems and also its conversion to other land uses such as forestry. It is clear that land use strategies have to consider factors such as food security, the provision of raw materials and biodiversity.

The EU Forest Action Plan (EC, 2006f) should also provide a positive contribution to soil protection by supporting and enhancing sustainable forest management and the multifunctional role of forests. Of particular significance are the key objectives relating to the maintenance and enhancement of biodiversity, carbon sequestration, integrity, health and resilience of forest ecosystems at various geographical scales.

Having recognised the environmental challenges of agricultural land use, in 2007 the European Parliament requested the European Commission to carry out a pilot project on 'Sustainable Agriculture and Soil Conservation through simplified cultivation techniques' (SoCo). [22] The SoCo report (JRC, 2009) concluded that there is a wide range of farming practices available to farmers throughout the EU for mitigating or even reversing soil degradation processes. In addition, there is a range of measures

[14] http://ec.europa.eu/agriculture/healthcheck/index_en.htm

within the current rural development policy (EAFRD)[15] that are appropriate for supporting sustainable soil management. These include national agri-environment measures and the provision of advice and training to farmers. Given the appropriateness of existing instruments, rural development policy should continue to address soil conservation needs. More work is needed to improve policy makers' and stakeholders' understanding of the appropriate reference levels that determine which agricultural practices farmers should adopt and are responsible for in line with the polluter pays principle, and those that produce public benefits beyond mandatory requirements and for which farmers should be remunerated. The development of reliable, comprehensive and operational indicators on (i) the state of soils (soil degradation); (ii) the social impact (cost) of soil degradation; and (iii) the impacts of soil protection, conservation and improvement practices, as encouraged in the proposed Soil Framework Directive, should be prioritised in order to produce a more accurate baseline estimate of the condition of European soils at the start of the next rural development programme. Soil conservation objectives should also be included more explicitly in the Rural Development Strategic Guidelines. For a more detailed overview, see Louwagie *et al*. (2011).

5.3 Mitigation and adaptation to climate change

The European Commission's White Paper, 'Adapting to climate change: Towards a European framework for action' (EC, 2009a) recognises the role that soils can play in providing essential resources for social and economic purposes under extreme climatic conditions, for example by improving the soil's carbon and water storage capacity, and conserving water in natural systems to alleviate the effects of droughts and prevent floods, soil erosion and desertification. Ecosystem services such as carbon sequestration, flood protection and protection from soil erosion, are directly linked to climate change, and healthy ecosystems are an essential defence against some of its most extreme impacts. But soils also have an important and untapped potential in terms of mitigation. With respect to agricultural soils, it has been estimated that the technical potential for mitigation through optimised carbon management of agricultural soils at EU-15 level is between 60–70 million tonnes CO_2 per year (EC, 2009b). While the level of implementation and mitigation potential of soil and land management options varies considerably from country to country, overall they have the advantage of being readily available and relatively low-cost, and not requiring unproven technology. In addition, while the potential of individual measures may be limited, the combined effect of several practices can make a significant contribution to mitigation (EC, 2009c).

5.4 Soil sealing and land take

The efficient protection of soils from further sealing can only be achieved by an integrated approach, requiring the full commitment of all policy levels, improving awareness and competence amongst concerned stakeholders, by abandoning counterproductive policies and by introducing legal requirements and/or clear financial incentives. In this context, the following three-tiered approach based on the 'prevent, limit, and compensate principle' has been proposed in a study carried out on behalf of the European Commission (Prokop *et al.*, 2011)[16]:

Tier 1: Prevention of soil sealing.

- establish the principle of sustainable development in spatial planning
- define realistic land take targets for the national and the regional level
- integrate the "prevent, limit, and compensate" principle for soil loss in all policy sectors

[15] http://ec.europa.eu/agriculture/rurdev/index_en.htm
[16] http://ec.europa.eu/environment/soil/sealing.htm.

• streamline existing funding policies accordingly (i.e. public funding for private housing, subsidies for developments on the green field sites, commuter bonuses, etc.)

According to regional needs the following key action lines could be proposed:

- steer new developments to already developed land
- provide financial incentives for the development of brownfield sites
- improve the quality of life in large urban centres
- make small city centres more attractive to counteract dispersed settlement
- develop structures in rural regions with shrinking population
- designate agricultural soils and valuable landscapes with development restrictions.

Tier 2: Limit soil sealing as far as possible

Whenever soil loss is unavoidable, mitigation measures should be implemented as far as possible by,

• respecting soil quality along planning processes and steering new developments towards less valuable soils

• applying technical mitigation measures to conserve some soil functions (i.e. permeable surfaces on parking areas).

Tier 3: Compensate soil losses

For specific infrastructure developments, it is inevitable that some top quality soils will be lost and valuable landscapes fragmented. In such cases, controlled compensation measures should be carried out to facilitate soil restoration measures elsewhere. This can be achieved by:

• establishing qualified compensation measures

• facilitating new opportunities.

5.5 A resource-efficient Europe

In September 2011, the European Commission set out a 'roadmap' aimed at transforming Europe's economy into a sustainable one by 2050 (EC, 2011a). The communication outlines how resource efficient growth is essential for the future well-being and prosperity of Europe. The roadmap identifies the economic sectors that consume the most resources, and suggests tools and indicators to help guide action in Europe and internationally. Within the roadmap, soil is identified as a key natural resource, with particular focus on food security and water management (both floods and drought). In relation to soil, the Commission will:

- call for the development of the scientific knowledge base on biotic material, land-use effects and trends, and spatial planning, leading to a Communication on land use by 2014;
- address indirect land use change resulting notably from the renewable energy policy;
- publish guidelines on best practices to limit, mitigate or compensate soil sealing;
- include broader resource efficiency considerations in the review of the Environmental Impact Assessment (EIA) Directive;.
- propose a candidate European Innovation Partnership on agricultural productivity and sustainability that aims to secure soil functionality at a satisfactory level (by 2020);
- request Member States to better integrate direct and indirect land use and its environmental impacts into their decision making processes and limit land take and soil sealing to the extent possible; implement actions needed to reduce erosion and increase soil organic matter; set up an inventory of contaminated sites and a schedule for remedial work (by 2015).

5.6 Biodiversity protection policy

Within the EU Biodiversity Strategy to 2020 (EC, 2011b), soil biodiversity is specifically addressed: "The Commission will continue its work to fill key research gaps, including on mapping and assessing ecosystem services in Europe, which will help improve our knowledge of the links between biodiversity and climate change, and the role of soil biodiversity in delivering key ecosystem services, such as carbon sequestration and food supply. Research funding under the new Common Strategic Framework could further contribute to closing identified knowledge gaps and supporting policy".

The commitment of the EU on soil biodiversity protection has been further supported by the International Convention on Biological Diversity, where its importance, for instance as a key player in sustainable agriculture, has been strengthened during the 2010 Conference of the Parties in Nagoya.

5.7 Research

A key pillar of the Soil Thematic Strategy is targeted research to develop the knowledge base underpinning policies that aim to ensure the sustainable use of soil. Several major soil-related projects have been financed within the FP7 programme. Examples include:

- BIOSOIL: A project launched in the context of the Forest Focus Regulation, has reported an increase in organic carbon in some European forest soils. (JRC, 2010)

- ECOFINDER (Ecological Function and Biodiversity Indicators in European Soils): increasing our knowledge of soil biodiversity and its role in ecosystem services, standardisation of methods and operating procedures for characterising soil biodiversity and functioning, the development of bioindicators and an assessment of the cost effectiveness of alternative ecosystem service maintenance policies. (www.EcoFINDERS.eu)

- ENVASSO: see section 5.8.

- GEOLAND2: Under the umbrella of the GMES programme, GEOLAND2 aims to demonstrate operational data processing lines that can provide land cover/use/change, as well as a range of bio-physical parameters to support European environmental policies. Soil sealing, erosion and food security are among the themes that are being developed. (www.gmes-geoland.info)

- GS SOIL: One of the key difficulties in assessing trends in soil properties at EU level is a lack of harmonised data. The INSPIRE Directive should facilitate data sharing and integration. The GS Soil project will assess and develop INSPIRE-compliant Geodata-Services for European soil data through state-of-the-art methodologies and best practice examples. (www.gssoil-portal.eu/)

- RAMSOIL: Identified a number of risk assessment methodologies for soil degradation processes, demonstrating comparability among different methodologies. (www.ramsoil.eu)

- SOILSERVICE: Aims to develop quantitative scenarios of long-term land use change across Europe and determine how soil nutrients can be retained, even after extensive use. SOILSERVICE makes predictions that link economy with production (food vs. biofuel), land use, soil biodiversity and sustainability. (www.kem.ekol.lu.se/soilservice)

- SoilTrEC: Aims to understand the rates of processes that dictate soil mass stocks and their function within the Earth's Critical Zone (CZ), the environment where terrestrial life flourishes and feeds most of humanity. In particular, SoilTrEC will establish four EU Critical Zone Observatories to study soil processes at field scale, develop a Critical Zone Integrated Model of soil processes/function and quantify impacts of changing land use, climate and biodiversity on soil functions and economic values. (www.soiltrec.eu/)

In addition, the Commission has published a number of focused reports outlining best practises for limiting soil sealing or mitigating its effects (Prokop *et al.,* 2011), for the management of soil organic matter (Gobin *et al.,* 2011) and on soil biodiversity (Turbé *et al*., 2009*).*

5.8 Indicators

Given the difficulties of measuring changes in soil characteristics and functions, focus is being placed on the development of indicators. The recent EU-funded ENVASSO project — ENVironmental ASsessment of Soil for mOnitoring (Kibblewhite *et al*., 2008) — investigated the feasibility of deriving indicators relating to the key threats to soil. The project identified a set of 27 priority indicators, with baseline and threshold values, that could be rigorously defined and implemented relatively easily to form a Europe-wide reference base that could be used to assess current and future soil status. Due to an inadequate scientific base or a lack of statistical data in many Member States, indicators for wind and tillage erosion, peat stocks, landslides, re-use of previously developed land, and progress in the management of contaminated land could not be defined. This lack of data highlights the requirement to establish harmonised monitoring networks with adequate updating intervals.

Interesting results are expected from the Eurostat LUCAS 2009 survey (Land Use/Cover Area frame Survey) on land cover, land use and agro-environmental indicators (Fig. 32). In the 2009 exercise, a specific soil module was added to provide information on a number of soil parameters and to test the methodology for a harmonised European monitoring of soil parameters for a whole range of statistical, research and policy purposes (Montanarella *et al*., 2010).

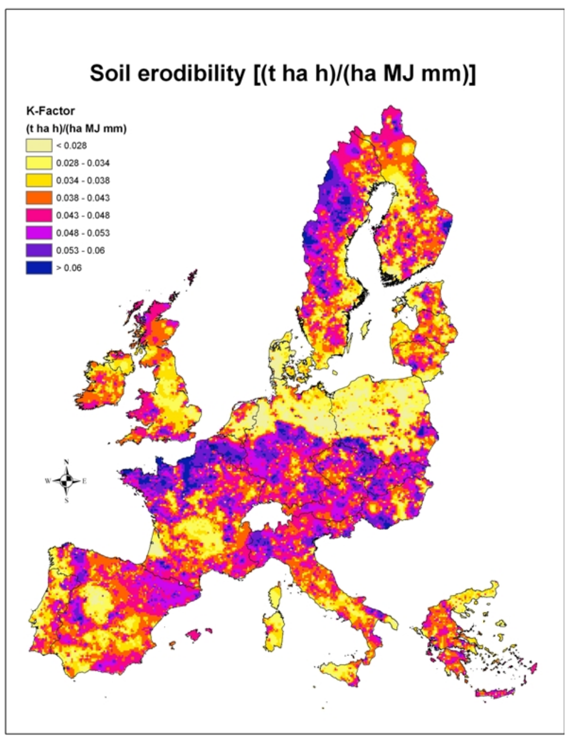

Figure 32: Soil erodibility, a key parameter for soil erosion modelling (the K- factor in the commonly used Universal Soil Loss Equation), based on soil data collected during the 2009 LUCAS survey.

Source: JRC/Panagos et al., 2011

5.9 Raising awareness

The Commission's Soil Thematic Strategy noted a marked lack of public awareness of the importance of soil and the need for soil protection. It stressed the need for measures to improve knowledge and exchange information on best practices to fill this gap. The JRC's European Soil Bureau Network has therefore established a Working Group on Public Awareness and Educational Initiatives for Soil. This group, together with initiatives from other interested groups (e.g. the European Land and Soil Alliance (ELSA), aims to improve this situation through targeted measures for key sectors (Towers *et al.,* 2010):

- **Education sector** - covering the ages from primary to tertiary level. By introducing soil science into the school curriculum from an early age it is possible to use 'hands-on' activities to explore and explain basic soil characteristics and functions such as: the different textures soil have - feel tests; what organisms live in soils - microscope work to study soil bugs and animals; soils in the garden - composting and growing plants.
- **Politicians, policy advisors and associated agencies** - through promoting awareness of soils across a number of sectors e.g. environment, agriculture, transport and energy, regional policy, development etc. There are a large number of EU and consequently national policies and strategies that involve soils across a number of thematic sectors; agriculture, forestry, waste management and climate change to name but a few.
- **Public stakeholder groups** - such as planners, the land based industries (primarily but not exclusively agriculture and forestry), gardeners, NGOs and then ultimately all citizens. Appropriate awareness-raising practices for dealing with soils should be developed to highlight the role of soils in sustaining our lives. A greater appreciation of the value and diversity of soils and the need to protect them should be promoted.

Figure 33: Soil awareness raising and education by the JRC (COP UNCBD, JRC Ispra Open Day). There is increasing realisation that the soil science community as a whole should enhance contact levels with the wider society as soil is often not bestowed with the same sense of importance as water or air quality.

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GLOSSARY / SUPPORTING INFORMATION

The numbers in this section correspond to the numbers in square brackets in the text (e.g. [2]).

1. **Soil** is a natural substance composed of weathered rock particles (minerals), organic matter, water and air. A typical sample of mineral soil comprises 45% minerals, 25% water, 25% air and 5% organic matter. These proportions can vary significantly according to the soil forming factors — parent material (predominantly geological), climate, biology (plants and soil fauna), landscape, time and human influences. Soil forming processes tend to be slow and occur over long periods of time — typical rates of soil formation under permanent grasslands in temperate climates is about 1–2 cm per 100 years. A soil body that is lost due to degradation process (e.g. erosion, pollution) would need hundreds or thousands of years to recover naturally. Compared to the lifespan of a human being, soil loss is not recoverable which means that we must regard soil as a non-renewable resource.

1b Major soil types of Europe

- Albeluvisols: Acid soils with bleached topsoil material tonguing into the subsoil
- Calcisols: Soils with significant accumulations of calcium carbonate
- Chernozems: Dark, fertile soils with organic-rich topsoil
- Fluvisols: Stratified soils, found mostly in floodplains and tidal Marshes
- Gleysols: Soils saturated by groundwater for long periods
- Gypsisols: Soils of dry lands with significant accumulations of Gypsum
- Histosols: Organic soils with layers of partially decomposed plant residues
- Kastanozems: Soils of dry grasslands with topsoil that is rich in organic matter
- Luvisols: Fertile soils with clay accumulation in the subsoil
- Leptosols: Shallow soils over hard rock or extremely gravelly material
- Umbrisols: Young, acid soils with dark topsoil that is rich in organic matter
- Vertisols: Heavy clay soils that swell when wet and crack when dry
- Phaeozems: Dark, moderately-leached soils with organic rich topsoil
- Podzols: Acid soils with subsurface accumulations of iron, aluminium and organic compounds
- Solonchaks: Soils with salt enrichment due to the evaporation of saline groundwater
- Stagnosols: Soils with stagnating surface water due to slowly permeable subsoil
- Planosols: Soils with occasional water stagnation due to an abrupt change in texture between the topsoil and the subsoil than impedes drainage

2. **Soil and raw materials**: Clay is used for making bricks for construction, pottery items (e.g. earthenware) and as the first writing medium (clay tablets). Due to its impermeable properties, clay is used as a barrier to stop water seeping away which is why many ponds, canals and landfill sites are lined with clay. Sand and gravel deposits, laid down by rivers fed by glaciers melting at the end of the last Ice Age, are very common through the northern circumpolar region. Both types of material are heavily used in the construction industry as aggregates while sand is the principal ingredient in glass making and used in sand-blasting to clean buildings and in sandbags to stop flooding. Like sand, gravel has countless uses. For example, in Russia, more roads are paved with gravel than with concrete or asphalt. In many countries, such as Scotland, Ireland and Finland, peat is used as a fuel. The peat is cut into rectangular blocks and stacked to remove moisture. When dry, the peat is burnt for heating and cooking. Peat is also dug into soil by gardeners to improve structure and enhance soil moisture retention. However, many people have become increasingly aware of the environmental impacts of peat extractions and are now looking for alternative, 'peat-friendly' composts.

3. **Soil and cultural heritage**: Waterlogged, very acid or permafrost-affected soils with low levels of oxygen have very little microbial activity and provide an ideal environment for preserving organic remains. Any disturbance of these environments, such as the drainage of wetlands or ploughing, changes the condition and leads to rapid decay and loss of the material. Archaeologists use these historical artefacts and the layers in which they are preserved to reconstruct the communities that produced them and the environments in which they lived. But to do this, the soil layers must remain undisturbed. Pollen grains of various plant species are often preserved in soil, especially peat. Analysis of the type and amount of pollen contained in a soil profile will provide a strong indication of the vegetation patterns over time, from which a record of past climate may be inferred. In northern regions, analysis of pollen records from peat deposits has shown that, as the glaciers retreated at the end of the last Ice Age, bare land was initially colonised by mosses, followed by a succession of grasses, dwarf shrubs, pine and birch trees.

4. **Soil organic carbon**: The amount of organic material stored in the soil can be expressed in two ways — as *organic matter* or *organic carbon*. The term *soil organic matter* (SOM) is generally used to describe the organic constituents in the soil, exclusive of undecayed plant and animal residues. The main component of SOM by weight is organic carbon. Therefore, s*oil organic carbon* (SOC) refers to the amount of carbon stored in the soil—it is expressed as weight of carbon by weight of soil (e.g. g C kg^{-1} soil). SOC is closely related to the amount of SOM, according to the approximation: SOC × 1.724 = SOM (Kononova, 1958).

To calculate the stock of C that is held in a given area (e.g. a field or even a country), the amount of soil in a given depth must be considered and are measured by determining the soil's bulk density (BD) and the depth of soil. Estimates of SOC stock will generally refer to a given depth of soil (e.g. the top 30 cm, 200 cm). The SOC stock (expressed as a weight: g, kg, tonnes) of a given volume of soil with the same soil characteristics can then be expressed as

SOC stock = SOC content of the soil x BD x area x depth

5. **Peat**: Peat forms in wetlands or peatlands, also referred to as bogs, fens, moors or mires. While many people often refer to 'peat bogs', peat can occur in a number of locations. A bog is a wetland that only receives water through rainfall and where organic matter accumulates under saturated, acidic conditions. Bog peat develops generally in areas with high rainfall where the moist ground conditions slow the decomposition of plant debris. As a consequence, organic matter accumulates and forms blanket peat or raised bogs. Bog peats are usually very acid as they do not obtain any buffering material from rivers and groundwater. Sphagnum, a type of moss, is one of the most common plants in raised bogs and forms a fibrous peat which often has a pH below 3. Fen peat develops in river valleys, flood plains and lakes where slowly flowing water or groundwater rising through the soil can be found. When the water becomes shallow, plants such as reeds and sedges become established. When the plants die, their waterlogged remains cover the soft deposits in which they grow and, over time, become peat. As rivers transport clay, silt and sand deposits, fen peat will often have a significant amount of mineral particles. The growth of peat and the degree of decomposition (or humification) depends principally on its composition and on the degree of waterlogging. Peat formed in very wet conditions accumulates considerably faster, and is less decomposed, than that in drier places. Peatlands usually accumulate at a rate of about a millimetre per year. This slow rate of growth must be taken in to consideration when people begin to exploit peat areas. Significant damage to peat areas may take hundreds or thousands of years to repair. This allows climatologists to use peat as an indicator of climatic change. The composition of peat can also be used to reconstruct ancient ecologies by examining the types and quantities of its organic constituents. Estimates of the mass of carbon stored globally in peatlands of the world range from 120 to 400 billion tonnes (Franzén, 2006). Therefore, peat soils are crucially important as a potential sink or source for atmospheric carbon dioxide.

6. **Water erosion** by rainfall, irrigation water or snowmelt, abrades, detaches and removes parent material or soil from one point on the Earth's surface to be deposited elsewhere; soil or rock material is detached and moved by water, under the influence of gravity by surface runoff in rills, inter-rills and sheet wash. Severe water erosion is commonly associated with the development of deep channels or gullies that can fragment the land.

7. **Wind erosion** is the removal of fine soil particles by moving air (deflation). A wind speed of 30–40 km h^{-1} is sufficient to dislodge particles from the soil and transport them either by being carried through the air (saltation) or rolling along the surface (creep). Dry, warm winds are more erosive than cold, humid winds as they reduce soil aggregate strength.

8. **Rates of soil erosion**: There has been much discussion in the scientific literature about thresholds above which soil erosion should be regarded as a serious problem. This has given rise to the concept of 'tolerable' rates of soil erosion that should be based on reliable estimates of natural rates of soil formation. However, soil formation processes and rates differ substantially throughout Europe. Considering the reported rates of soil formation, it appears reasonable to propose, from a scientific viewpoint, a global upper limit of approximately 1 t ha^{-1} yr^{-1} for mineral soils (see ENVASSO Report — Huber *et al.,* 2008). Even though under specific conditions (e.g. extremely high precipitation combined with high temperatures) actual soil formation rates can be substantially greater, it would nevertheless be advisable to apply a precautionary principle to any assessment; otherwise soils with particularly slow rates of formation will steadily disappear.

9. **Evidence of water erosion**: video of 2010 flooding and erosion in Madeira

http://news.bbc.co.uk/2/hi/europe/8527589.stm (accessed 11 January 2012).

10. **PESERA model**: The model results have been validated at catchment level and compared with results of applying other erosion risk assessment methods across Europe at country and pan-European scale. However, further development of the model and a substantial amount of calibration and validation work are essential if PESERA is to become operational. Preliminary results suggest that, although the model can be applied at regional, national and European levels, low resolution and poor quality input data cause errors and uncertainties. However, quantification of the erosion problem enables evaluation of the possible effects of future changes in climate and land use, through scenario analysis and impact assessment taking into account cost-effectiveness, technical feasibility, social acceptability and possibilities for implementation. Soil erosion indicators developed from a physically based model will not only provide information on the state of soil erosion at any given time, but also assist in understanding the links between different factors causing erosion. Another advantage for policy making is that scenario analysis for different land use and climate change is possible using PESERA. This will enable the impacts of agricultural policy, and land use and climate changes to be assessed and monitored across Europe.

http://eusoils.jrc.ec.europa.eu/ESDB_Archive/Pesera/pesera_cd/index.htm
(accessed 11 January 2012).

11. Compaction: Topsoil compaction refers to the compaction of the upper 20–35 cm of the soil profile. In most cases the topsoil has greater organic matter content, contains many more roots and supports a much greater biological activity than the subsoil. Also, physical processes such as wetting, drying, freezing and thawing are more intense in the topsoil than in the subsoil. Consequently, natural loosening processes are much more active and stronger in the topsoil than in the subsoil. This makes topsoil more resilient to compaction than the subsoil. Subsoil compaction, normally below a depth of 30 cm, often takes the form of a plough pan which is caused by the wheels of tractor being in direct contact with the subsoil during ploughing or by heavy wheel loads that transmit the pressure through the topsoil into the subsoil. Huber *et al*. (2008) describes five indicators and thresholds to assess compaction.

12. Salt-affected soils occur mainly in the arid and semi-arid regions of Asia, Australia and South America, and cover fewer territories on other continents (e.g. in Europe). Salinity, the build up of water-soluble salts; alkalinity, reflected in increasing soil pH; and sodicity, the build up of sodium, are among the most widespread soil degradation processes and sources of environmental / ecological stress. European salt-affected soils occur south of a line from Portugal to the Upper Volga including the Iberian Peninsula, the Carpathian Basin, Ukraine, and the Caspian Lowland. A distinction can be made between primary and secondary salinisation processes. Primary salinisation involves accumulation of salts through natural processes such as physical or chemical weathering and transport from saline geological deposits or groundwater. Secondary salinisation is caused by human interventions such as inappropriate irrigation practices, use of salt-rich irrigation water and/or poor drainage conditions.

13. Acidification: Soils will become more acid if there is (i) a source of H^+ ions to replace base cations removed by ion exchange processes or (ii) a means of removing the displaced base cations (achieved by a mobile anion such as sulphate (SO_4^{2-}) or nitrate (NO_3^-)). The acidification of soils can be a natural, long term process. Plants take base cations from the soil as nutrients, humic acids from litter can mobilise base elements which are then more easily leached from the soil, while the harvesting of high yield crops limits the return of base cations to the soil as the majority of the 'litter' is removed for processing. Acid deposition from industrial emissions can accelerate the process. In general, soil acidification can be described as a two-step process:

- The slow gradual depletion of base cations (nutrients for vegetation), that is the leaching of calcium (Ca^{2+}), magnesium (Mg^{2+}) and bases - such as hydrogen carbonate (HCO_3) and carbonate (CO_3^{2-});
- Their replacement by 'acidic' hydrogen (H^+), aluminium, iron and manganese ions and complexes.

While H^+ is mainly supplied by atmospheric deposition and ecosystem internal processes, the 'acidic' metal cations are released from the bedrock by mineral weathering.

Weathering of parent material is the main way in which cations are replenished, but other soil processes such as adsorption and microbial reduction of sulphates (SO_4) can also help to ameliorate acidification. An important consequence of acidification is an enhanced level of aluminium ions in the soil solution. In many cases, the increased mobility of aluminium can have significant effects on ecosystems. High levels of soluble Al^{3+} at very low pH values disrupt cell wall structure in plant roots and inhibit nutrient uptake (Kennedy, 1992). Al^{3+} can also kill earthworms at high concentrations (Cornelis and van Gestel, 2001) and leach into water, affecting aquatic life.

14. Critical Loads: The critical load of sulphur and nitrogen acidity is defined as the highest deposition of acidifying compounds that will not cause chemical changes leading to long term harmful effects on ecosystem structure and function. Target ecosystems can be forests (for example in Central Europe) or freshwaters (for example in the Nordic Countries). For forest soils, the chemical criterion for setting the critical load, a flux given in equivalents acidity (H^+) per hectare and year (eq ha^{-1} yr^{-1}), is the base cation (BC) to aluminium (Al^{3+}) ratio in soil water. A critical limit for this ratio has been defined ($BC/Al^{3+} = 1$).

15. Desertification is closely associated with a wide set of degradation processes (Brandt & Thornes, 1996; Rubio & Recatala, 2006; Safriel 2009) including decline in soil organic matter, soil erosion, soil salinisation, decline in soil biodiversity, over-exploitation of groundwater, wild fires (forest, scrub and grass fires), soil contamination and even uncontrolled urban expansion (Sommer *et al*., 1998). Several studies (Yassoglou, 1999) have confirmed the closer links between vegetation degradation (i.e. overgrazing, forest fires) and soil degradation as drivers of increasing soil erosion rates. Therefore, desertification is a cross-cutting issue and the countries in Europe most affected are Spain, Portugal, southern France, Greece, Cyprus, Malta and southern Italy. Parts of other countries, especially in central Europe, may also meet the criteria of desertification largely through 'aridification', where the ground water level has been lowered by over-exploitation, or intensive drainage has dried out the land, and prolonged periods without rainfall follow.

16. **Landslides** will occur when the inherent resistance of the slope is exceeded by the forces acting on the slope such as excess rainfall, snow melt or seismic activity, or as a consequence of human interference with the shape of the slope (e.g. constructing over-steepened slopes) or modifying the soil/bedrock conditions and groundwater flow, which affects slope stability. Landslides occur more frequently in areas with steep slopes and highly erodible soils, clayey sub-soil, weathered and jointed bedrock, following intense and prolonged precipitation, earthquakes (in southern Europe) or rapid snowmelt. Locally, manmade slope cutting and loading can also cause landslides. Landslides are usually classified on the basis of the material involved — rock, debris, earth, mud — and the type of movement — fall, topple, slide, flow, spread. Landslides threaten soil functioning in two ways: i) removal of soil from its in situ position, and ii) covering the soil downslope from the area where the slope has 'failed'. Where a landslide removes all soil material, all soil functions will be lost and weathering processes of the hard rock, or sediment, now exposed at the surface, need to operate for hundreds if not thousands of years to produce enough soil material for soil functioning to resume. When only a part of the soil profile (e.g. the A horizon) is removed by a landslide, some soil functions may remain, although most functions are likely to be impaired.

17. **Graphic examples of landslides -** Calabria, Italy — February 2010.
http://www.youtube.com/watch?v=BmO_YLVjMCY

Cornwall, UK, October 2011
http://www.bbc.co.uk/news/uk-15251292

http://www.gsi.ie/Programmes/Quaternary+Geotechnical/Landslides/Landslide+Event+Gallery.htm

(all accessed 11 January 2012).

18. **Local contamination and contaminated sites**: Local soil contamination occurs where intensive industrial activities, inadequate waste disposal, mining, military activities or accidents introduce excessive amounts of contaminants. If the natural soil functions of buffering, filtering and transforming are overexploited, a variety of negative environmental impacts arise; the most problematic are water pollution, direct contact by humans with polluted soil, uptake of contaminants by plants and explosion of landfill gasses (EEA, 2007). Management of contaminated sites is a tiered process starting with a preliminary survey (searching for sites that are likely to be contaminated), followed by performing site investigations where the actual extent of contamination and its environmental impacts are defined, and finally implementing remedial and after care measures. The term 'contaminated sites' is used to identify sites where there is a confirmed presence, caused by human activities, of hazardous substances to such a degree that they pose a significant risk to human health or the environment, taking into account land use (EC, 2006e).

19. **Diffuse soil contamination** is the presence of a substance or agent in the soil as a result of human activity emitted from moving sources, from sources with a large area, or from many sources. Diffuse soil contamination is caused by dispersed sources, and occurs where emission, transformation and dilution of contaminants in other media has occurred prior to their transfer to soil. The three major pathways responsible for the introduction of diffuse contaminants into soil are atmospheric deposition, agriculture and flood events. Causes of diffuse contamination tend to be dominated by excessive nutrient and pesticide applications, heavy metals, persistent organic pollutants and other inorganic contaminants. As a result, the relationship between the contaminant source and the level and spatial extent of soil contamination is indistinct.

20. **IPCC Climate Change Scenarios:** In 2000, the United Nations Intergovernmental Panel on Climate Change (IPCC) prepared a Special Report on Emissions Scenarios (SRES) (IPCC, 2000b). This study presented four major emission storylines that could be used for driving global circulation models and to develop climate change scenarios. The main characteristics of each scenario are listed below:

A1
- Rapid economic growth.
- A global population that reaches 9 billion in 2050 and then gradually declines.
- The quick spread of new and efficient technologies.
- A convergent world — income and way of life converge between regions.

A2
- A world of independently operating, self-reliant nations.
- Continuously increasing population.
- Regionally oriented economic development.
- Slower and more fragmented technological changes and improvements to per capita income.

B1
- Rapid economic growth as in A1, but with rapid changes towards a service and information economy.
- Population rising to 9 billion in 2050 and then declining as in A1.
- Reductions in material intensity and the introduction of clean and resource-efficient technologies.

- An emphasis on global solutions to economic, social and environmental stability.

B2

- Continuously increasing population, but at a slower rate than in A2.
- Emphasis on local rather than global solutions to economic, social and environmental stability.
- Intermediate levels of economic development.
- Less rapid and more fragmented technological change than in A1 and B1.

21. EU Soil Thematic Strategy: The Commission adopted a Soil Thematic Strategy (COM(2006) 231) and a proposal for a Soil Framework Directive (COM(2006) 232) on 22 September 2006 with the objective to protect soils across the EU. The legislative proposal has been sent to the other European Institutions for further implementation, but has not been adopted so far. To achieve the Strategy's objectives, Member States are required to identify risk areas for erosion, organic matter decline, compaction, salinisation and landslides, on the basis of common criteria set out in the directive. They will set risk reduction targets for those risk areas and establish programmes of measures to reach them. These measures will vary according to the severity of the degradation processes, local conditions and socioeconomic considerations. As far as contamination is concerned, the Member States will identify the relevant sites in their national territory. They will establish a national remediation strategy on the basis of an EU-wide definition and of a common list of potentially polluting activities. They will have to create a mechanism to fund the remediation of orphan sites. Anyone selling or buying a site where potentially contaminating activity has taken or is taking place, will have to provide to the administration and to the other party in the transaction a soil status report. The proposed Soil Framework Directive also addresses the prevention of diffuse contamination by limiting the introduction of dangerous substances into the soil. Member States are also required to limit sealing, for instance by rehabilitating brownfield sites, and mitigate its effects by using construction techniques that preserve as many soil functions as possible.

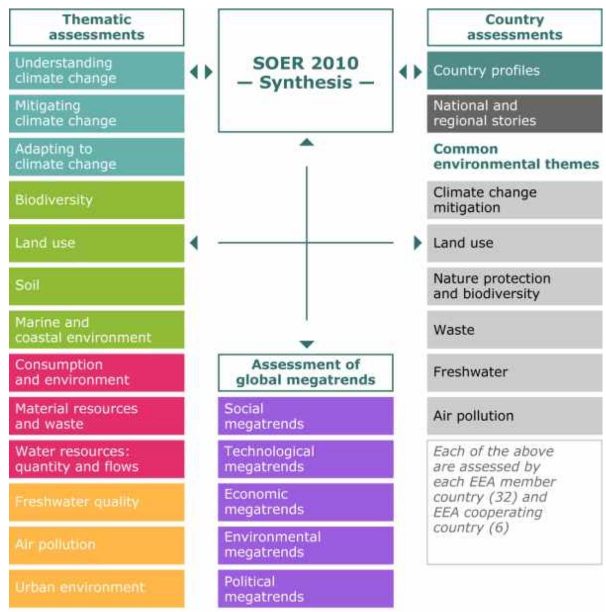
http://ec.europa.eu/environment/soil/index_en.htm (accessed 11 January 2012).

22. SoCo: The project reviewed soil degradation processes, soil conservation practices and policy measures at European level. The analysis was applied to the local scale by means of ten case studies distributed over three macro-regions. The environmental benefits of adopting particular soil conservation practices were modelled. Finally, the report discussed the relevance, effectiveness and efficiency of instruments for soil protection in Europe, and opportunities and critical issues linked to the adoption of conservation practices.

http://soco.jrc.ec.europa.eu/index.html (accessed 11 January 2012).

23. SOER 2010: An assessment of the state and outlook of the European Environment produced by the European Environment Agency. Usually generated every five years, the report describes the knowledge and understanding of the state of environment in Europe and the main trends, outlook and policy responses. The 2010 Report contains a specific assessment on soil.

http://www.eea.europa.eu/soer (accessed 11 January 2012).



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Abstract
This report presents a pan-European perspective on the state soil in Europe in light of available data held within the European Soil Data Centre (ESDAC) and the research activities within the Joint Research Centre's Soil Action. Managed by the JRC on behalf of EU institutions, the ESDAC operates as a focal point for pan-European data and information on soil. The core of this report was prepared as the Soil Assessment of the 'Environment — state and outlook 2010 Report', generally referred to as the SOER 2010. Coordinated by the European Environment Agency, the SOER series is aimed primarily at policymakers, in Europe and beyond, involved with framing and implementing policies that could support environmental improvements in Europe. The information also helps European citizens to better understand, care for and improve Europe's environment. The soil assessment was one of a set of 13 Europe-wide thematic assessments of key environmental themes and the only one coordinated by the JRC. The initial contribution from the JRC to the SOER exercise has been updated with additional material that could not be included in the SOER due to space restrictions, together with supplementary information that was not available at the time of the publication of the original text.

The report describes the knowledge and understanding of the state of soil in Europe and the main trends, outlook and policy responses for the key processes affecting soil resources in Europe. Unfortunately, our knowledge base on many of the key functions of soil that deliver vital environmental services and goods are still poorly developed. This aspect will be a key focus of the activities of the Soil Action for the next SOER, foreseen for 2015. A set of pertinent issues and facts from the assessment are presented in the Key Messages section at the start of this report.

Much more information and data can be found that the web sites of the ESDAC (http://esdac.jrc.ec.europa.eu) or the JRC Soil Action (http://eusoils.jrc.ec.europa.eu).

All SOER 2010 outputs are available on the SOER 2010 website: www.eea.europa.eu/soer.

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