THE EUROPEAN ENVIRONMENT

STATE AND OUTLOOK 2010

SOIL

Contribution to SOER 2010 by JRC EUROPEAN COMMISSION

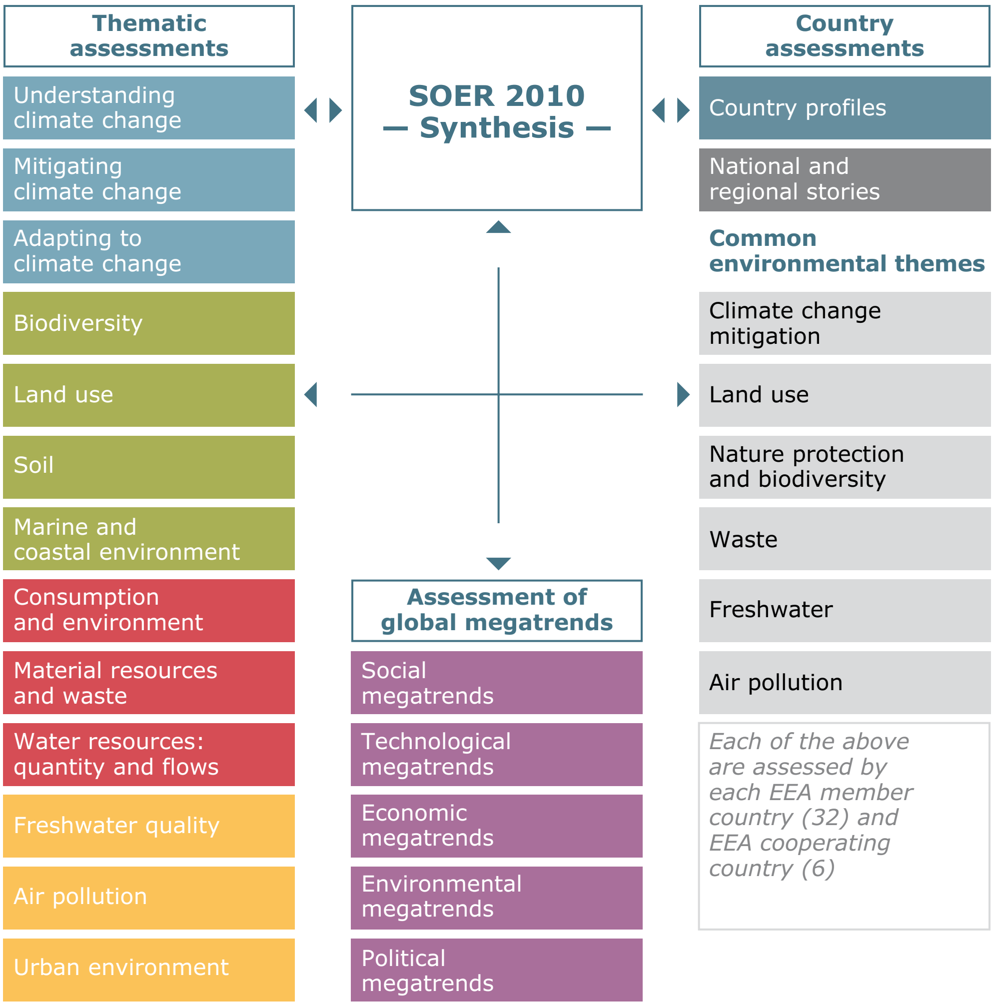
What is the SOER 2010?

The European environment — state and outlook 2010 (SOER 2010) 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 SOER 2010 'umbrella' includes four key assessments:

1. a set of 13 Europe-wide **thematic assessments** of key environmental themes;
2. an exploratory assessment of **global megatrends** relevant for the European environment;
3. a set of 38 **country assessments** of the environment in individual European countries;
4. a **synthesis** — an integrated assessment based on the above assessments and other EEA activities.

SOER 2010 assessments



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Soil

Summary

Nearly all of the food 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 in many parts of Europe is being over-exploited, degraded and irreversibly lost due to impacts from industrial activities and land use change, leading to soil sealing, contamination, erosion and loss of organic carbon. Due to these problems, legislation for the protection of soils has been proposed at EU level.

Soil is defined as the top layer of the earth's crust. It is composed of mineral particles, organic matter, water, air and living organisms — a non-renewable resource which performs many vital functions. Soil has a role as a habitat and gene pool; serves as a platform for human activities, landscape and heritage; and acts as a provider of raw materials. These functions are worthy of protection because of their socio-economic as well as environmental importance.

The soil resources of Europe are diverse, reflecting a combination of geology, climate, topography and land use developed over thousands of years. Northern European soils tend to have higher organic matter content than those in the south. Relatively young soils dominate central Europe. Poorly developed soils or soil with accumulations of calcium carbonate characterise the Mediterranean basin. The slow rates of soil formation mean that soil must be regarded as essentially non-renewable. The unsustainable human use and management of land is leading to increased soil degradation and a loss of a key resource that is fundamental to life on the planet.

Different EU policies for water, waste, chemicals, industrial pollution prevention, nature protection, pesticides and agriculture are contributing to soil protection. However, as these policies have other aims and other scopes of action, they are not sufficient to ensure an adequate level of protection for all soil in Europe. 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) on 22 September 2006 with the objective to protect soils across the EU.

Soil degradation: state, trends and impacts

- 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.
- Organic matter decline: the soils of EU-27 Member States store about 79 billion tonnes of carbon. The storage capacity of soil is sensitive to climatic conditions and there is a high risk that global warming will turn soils into a major source of greenhouse gases. Some 45 % of soils in Europe have a low or very low organic matter content (meaning 0–2 % organic carbon) and 45 % have a medium content (meaning 2–6 % organic carbon). This issue is found especially in southern European countries, as well as in parts of France, the United Kingdom, Germany, Norway and Belgium.
- Compaction: the use of heavy machinery in agriculture can induce soil compaction. It 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 36 % of European subsoils as having high or very high susceptibility to compaction. Other sources report 32 % of soils being highly vulnerable and 18 % moderately affected.

- Salinisation stands for the accumulation of salts and other substances from irrigation water and fertilizers which makes soils unsuitable for plant growth. It affects approximatly 3.8 million ha in Europe. The main driver is the inappropriate management of irrigated agricultural land.
- Landslides occur more frequently in areas with: highly erodible soils or clay-based sub-soils; steep slopes; intense and abundant precipitation; or abandoned terraces, such as the Alpine and Mediterranean regions. Until now there are no data on the total area affected in the EU.
- Contamination: due to more than 200 years of industrialisation, soil contamination is a wide-spread 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.
- Sealing occurs when agricultural or other non-developed land is built on. It normally includes the removal of top soil layers and leads to the loss of important soil functions, such as food production or water storage. On average, built-up and other man-made areas take up around 4 % of the total area in EEA countries (data exclude Greece, Switzerland and the United Kingdom), but not all of this is actually sealed. In the decade 1990–2000 the sealed area in the EU-15 increased by 6 %, and productive soil continues to be lost to urban sprawl and transport infrastructures.
- Biodiversity decline: soil biodiversity is built on a great variety of soil organisms from bacteria to mammals that shape the metabolic capacity of the ecosystem and many other functions of soils. Soil biodiversity is affected by all of the degradation processes listed above, and all driving forces mentioned apply (equally) to the loss of soil biodiversity.

1 Introduction

Soil is a vital natural resource that regulates our environment and responds to a range of pressures imposed upon it [1]. The soil resources of Europe are diverse (see Map 1.1). Northern European soils tend to have higher organic matter contents than those in the south. Relatively young soils dominate central Europe, and poorly developed soils or soil with accumulations of calcium carbonate characterise 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 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 soil functions.

- Soil is the medium that enables us to grow food for people or animals, natural fibre, and timber, and supports wildlife. Around 99 % of global food supplies (calories) for human consumption come from land-based food production (FAO, 2007).

- Soil is a natural filter that neutralises certain pollutants by transforming them or accumulating and absorbing their toxicity. In addition, soils are a major factor in purifying water supplies and are a critical component for regulating flooding through the storage of rainfall. The sealing and compaction of permeable soils results in a more rapid delivery of rainfall to the river network. These are just examples of the critical ecosystem services provided by soil.

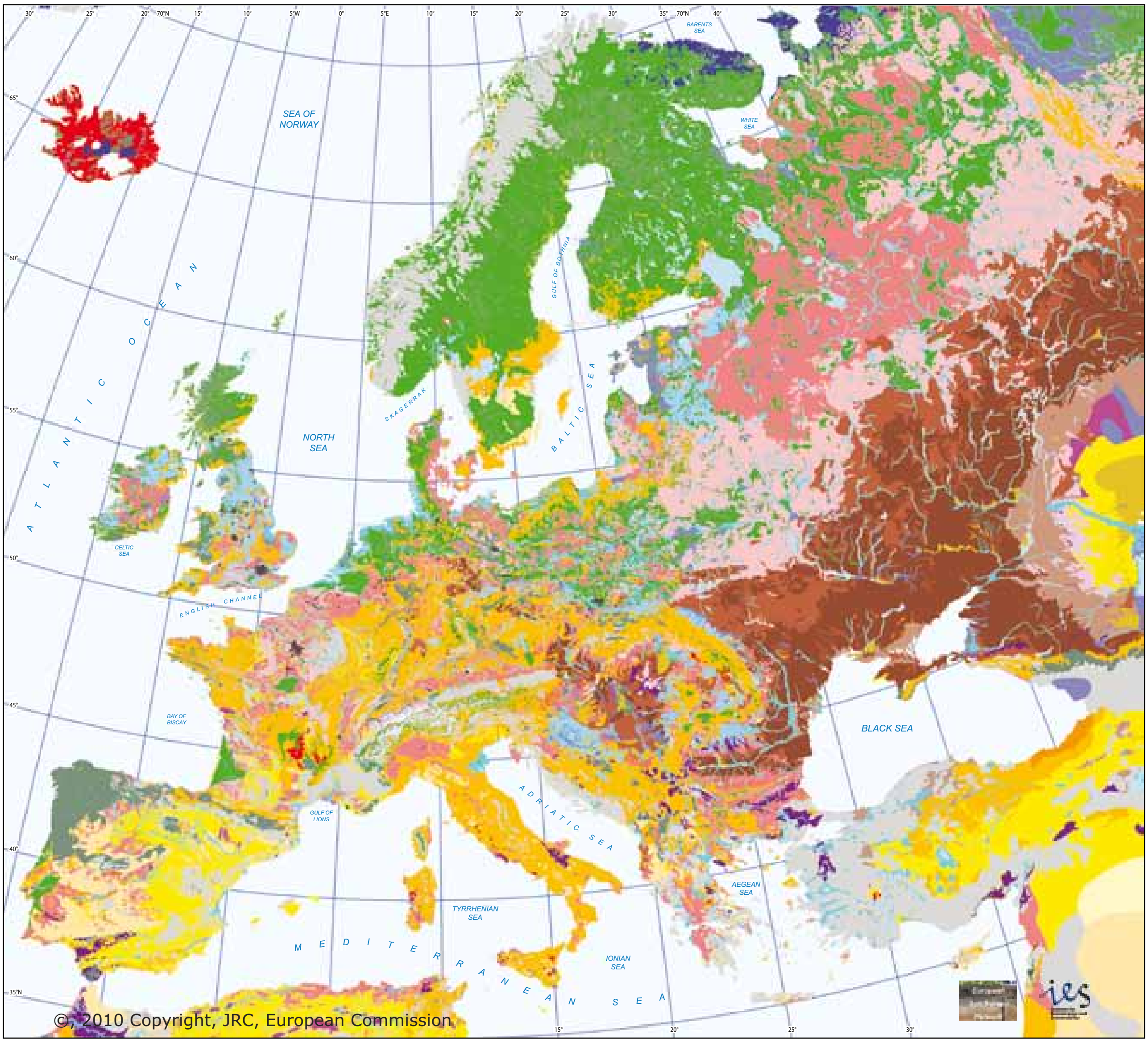
- Soil is a biological engine where dead plant and animal tissues, and other organic wastes, are decomposed to provide nutrients that sustain life. Soil is alive: decomposition processes are driven by a mass of soil microorganisms. A handful of soil may contain more than 10 billion microorganisms (Torsvik and Ovreas, 2002), the majority of which are bacteria — comparable to the number of people on Earth! In addition to the huge amounts of bacteria, 1 m^3 of fertile topsoil will 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 exceed that of a medium-sized elephant — five tonnes — 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 also represent a crucially important 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, ground water and the atmosphere. The intensity of these bio-geochemical exchanges varies from place to place and is regulated by soil characteristics.

- 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 [2]. Soils that preserve cultural heritage should also be regarded as valuable.

- Soil provides the foundation on which we construct our 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. [3]

Map 1.1 The major soil types of Europe



- Albeluvisols: Acid soils with bleached topsoil material tonguing into the subsoil
- Arenosols: Soils developed in quartz-rich, sandy deposits such as coastal dunes or deserts
- Cambisols: Young soils with moderate horizon development
- Cryosols: Soil influenced by permafrost or cryogenic processes
- Gleysols: Soils saturated by groundwater for long periods
- Histosols: Organic soils with layers of partially decomposed plant residues
- Andosols: Young soils developed in porous volcanic deposits
- 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
- Gypsisols: Soils of dry lands with significant accumulations of gypsum
- Kastanozems: Soils of dry grasslands with topsoil that is rich in organic matter
- Leptosols: Shallow soils over hard rock or extremely gravelly material
- Luvisols: Fertile soils with clay accumulation in the subsoil
- Phaeozems: Dark, moderately-leached soils with organic rich topsoil
- Vertisols: Heavy clay soils that swell when wet and crack when dry
- Podzols: Acid soils with subsurface accumulations of iron, aluminium and organic compounds
- Regosols: Young soils with no significant profile development
- Solonchaks: Soils with salt enrichment due to the evaporation of saline groundwater
- Solonetz: Alkaline soils with clayey, prismatic-shaped aggregates and a sodium-rich subsurface horizon
- Stagnosols: Soils with stagnating surface water due to slowly permeable subsoil
- Technosols: Soils containing significant amounts of human artefacts or sealed by impermeable material
- Umbrisols: Young, acid soils with dark topsoil that is rich in organic matter
- Planosols: Soils with occasional water stagnation due to an abrupt change in texture between the topsoil and the subsoil than impedes drainage

Source: JRC/ESDAC.

2 State and trends

2.1 Determining the state and trends of soil functions

Soil functions occur 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 pan-European assessment of soil state 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 may not contain 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, many of these networks reflect national priorities and standards, making the comparison of their results with those of other countries difficult. Many countries have no provision for the systematic collection of soil data.

Photo 2.1 Soils provide a myriad of 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

Consequently, there is a difficulty in applying 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 using assumptions about the ability of specific soil types to provide certain functions. In a simplistic example, sandy soils allow the easy drainage of surface water but crops grown on these soils can suffer during periods of drought as the water storage capacity is low. 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 Determining the state and trends of threats to soil

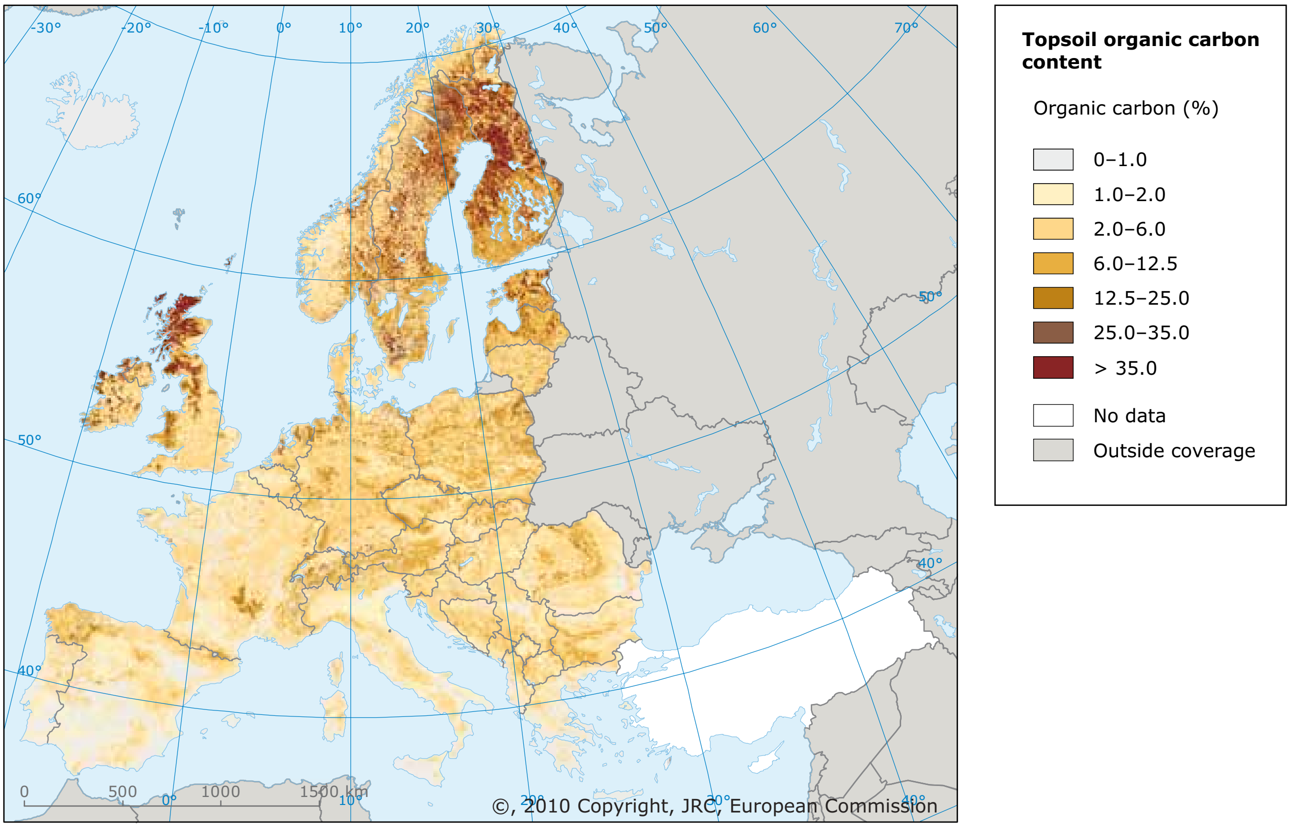
Widespread soil degradation, leading to a decline in the ability of soil to carry out its ecosystem services, is caused largely by non-sustainable uses of the land over a long time span. This has also marked local, regional, European and global impacts. Soil degradation contributes to food shortages, 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 assessment (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.

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. 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). Low levels exist in particular 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 mineralization 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, regions of 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} (for reference, while rates vary from crop to crop, the IRENA Indicator 08 — Mineral fertiliser consumption — estimates average application rates of nitrogen fertiliser for EU-15 in 2000 ranged from 8–179 kg N ha^{-1} (EEA, 2005a)).

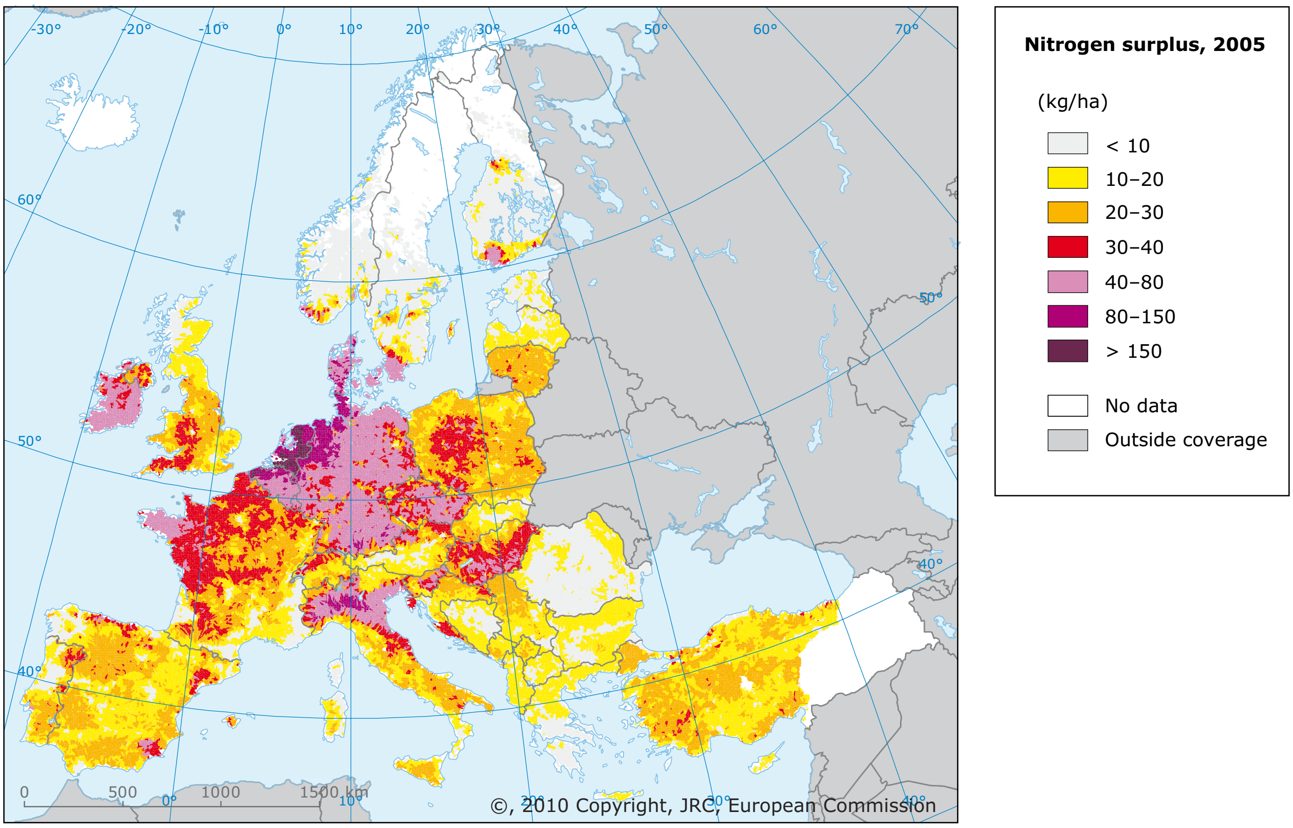
Map 2.1 Variations in topsoil organic carbon content (%) across Europe



Note: The darker regions correspond to higher values of organic matter. The darkest colours, especially in Ireland, the United Kingdom and Scandinavia denote peatlands.

Source: JRC: Jones et al., 2005.

Map 2.2 Estimated nitrogen surplus across Europe, 2005



Note: 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 mineralization 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 around 75 billion tonnes of carbon (C), of which about 50 % is in Sweden, Finland and the United Kingdom because of their large areas of peatlands and forest soils (Schils et al., 2008).

Peat soils represent the highest concentration of organic matter in all soils [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 65 000 km^2 or 20 % of all peatlands, have been drained for agriculture, almost 90 000 km^2 or 28 % for forestry and 2 273 km^2 or 0.7 % 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 Mt C yr^{-1} (Gundersen et al., 2006).

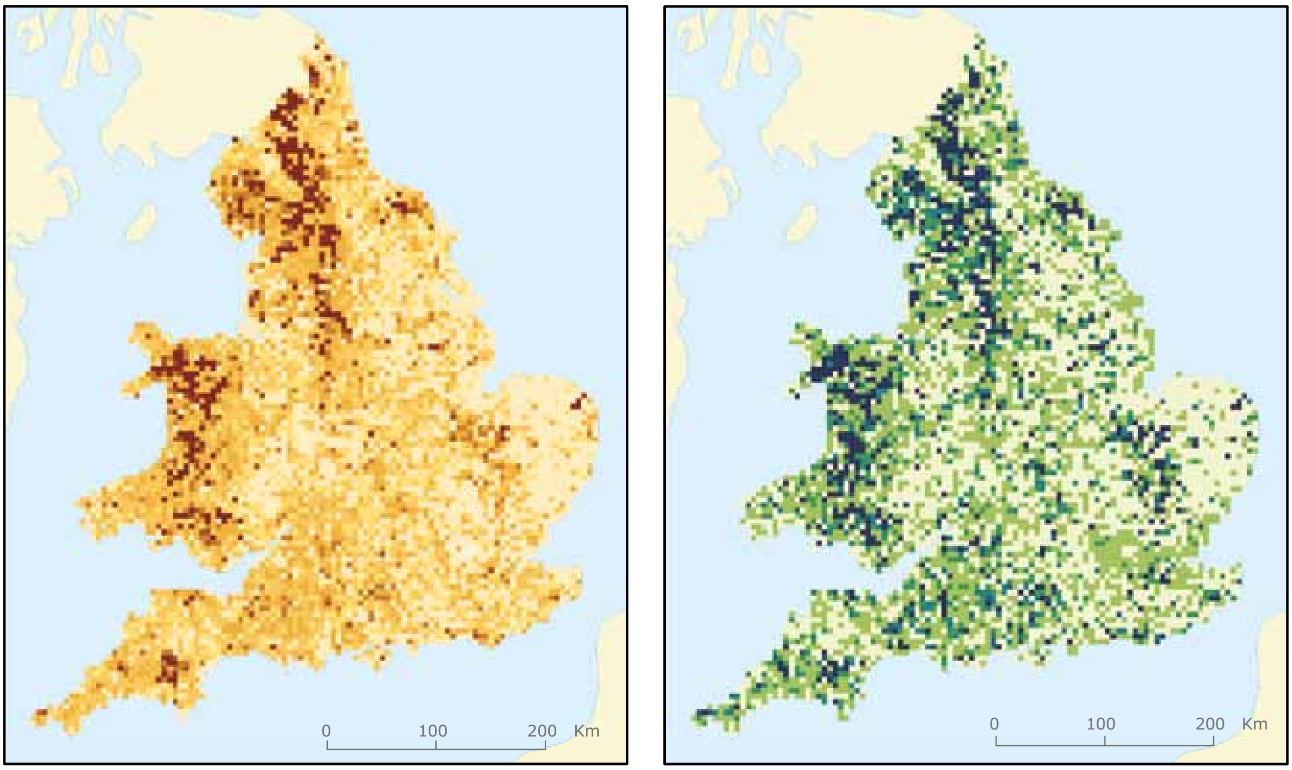
- Trends in soil organic carbon levels: In general, soils lose carbon through cultivation and disturbance. Changes in soil organic carbon content (SOC) are expected to be faster in topsoil (0–30 cm) than in deeper soil. An assessment of carbon stocks is a reliable approach to provide an indication of changes in organic matter. Comparisons of carbon stocks should always take into consideration the soil type and land management practices.

Except for the rapid removal of SOC by erosion and landslides, changes in SOC levels as a result of the intensification of agriculture, deforestation or conversion of grassland to arable land are slow processes. This makes changes difficult to assess. 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. Similar trends were observed in France, Belgium and Sweden (Saby et al., 2008; Goidts et al., 2009) and it appears that the rate of change is proportional to the initial soil organic carbon content. SOM decline is also of particular concern in the Mediterranean region (Jones et al., 2005) where high temperatures and droughts could accelerate the decomposition of soil organic matter.

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 recently completed Biosoils project, carried out under the Forest Focus Regulation, with previous pan-European forest surveys should provide new information on trends in soil organic carbon levels in European forests (JRC, 2010a).

Map 2.3 Changes in soil organic carbon content across England and Wales between 1978 and 2003



Change in soil organic carbon contents across England and Wales between 1978 and 2003

Left: carbon contents in the original samplings (1978–1983)

Original C_{org} (g/kg)

< 20 | 20–30 | 30–50 | 50–100 | 100–200 | 200–300 | > 300

Right: rates of change calculated from the change over the different sampling intervals (1994–2003)

Rate of change (g/kg/yr)

< –2.0 | –2.0 to –1.5 | –1.5 to –1.0 | –1.0 to –0.5 | –0.5 to 0.0 | > 0.0

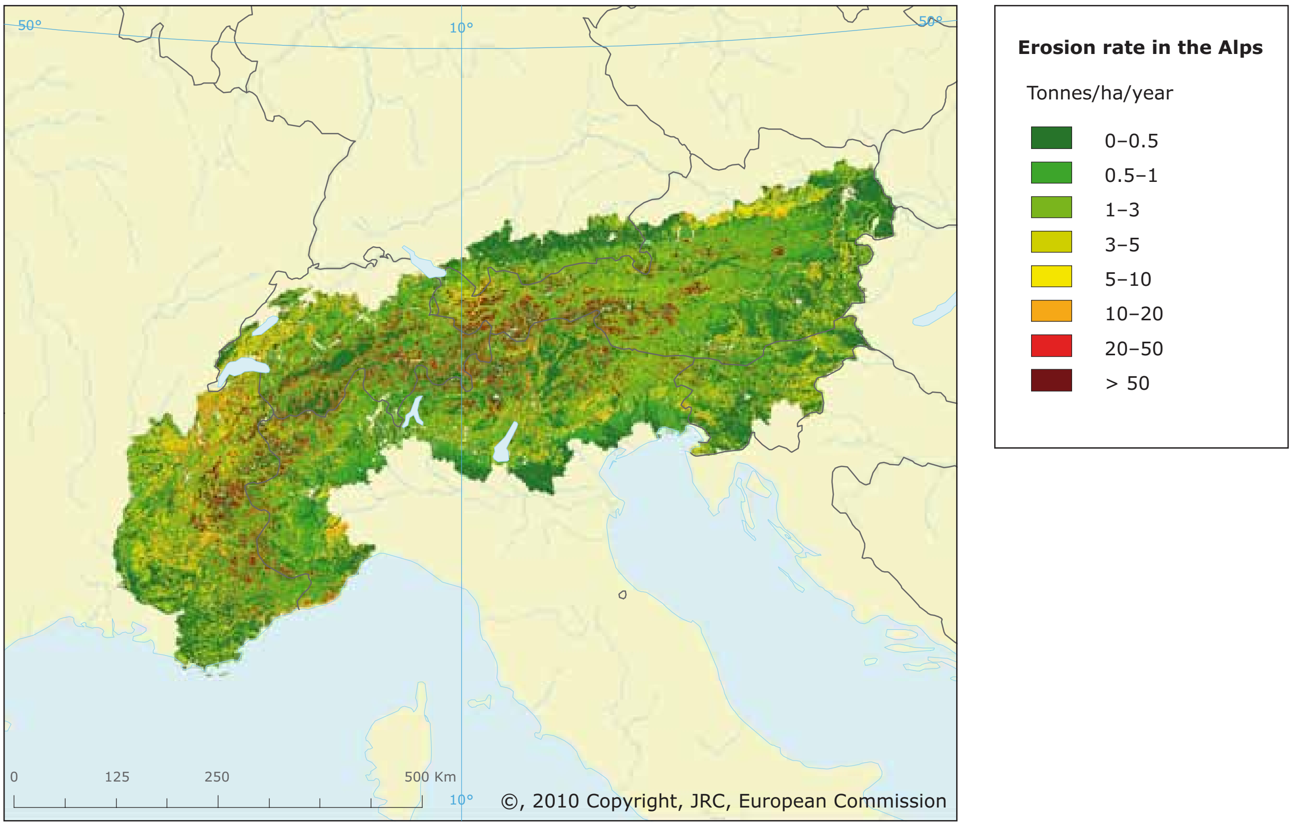
Source: Bellamy et al., 2005.

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 practice at field level. With the very slow rate of soil formation, any soil loss of more than 1 t ha^{-1} yr^{-1} can be considered as irreversible within a time span of 50–100 years (Huber et al., 2008) [8].

- **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). No harmonised measure of actual soil erosion rates exist for the European continent. To date, the only harmonised Europe-wide estimates of soil erosion by water have been provided by 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.
- 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.

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

Map 2.4 Erosion rate in the Alps



Note: 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 (> more than 10 t ha^{-1} yr^{-1}).

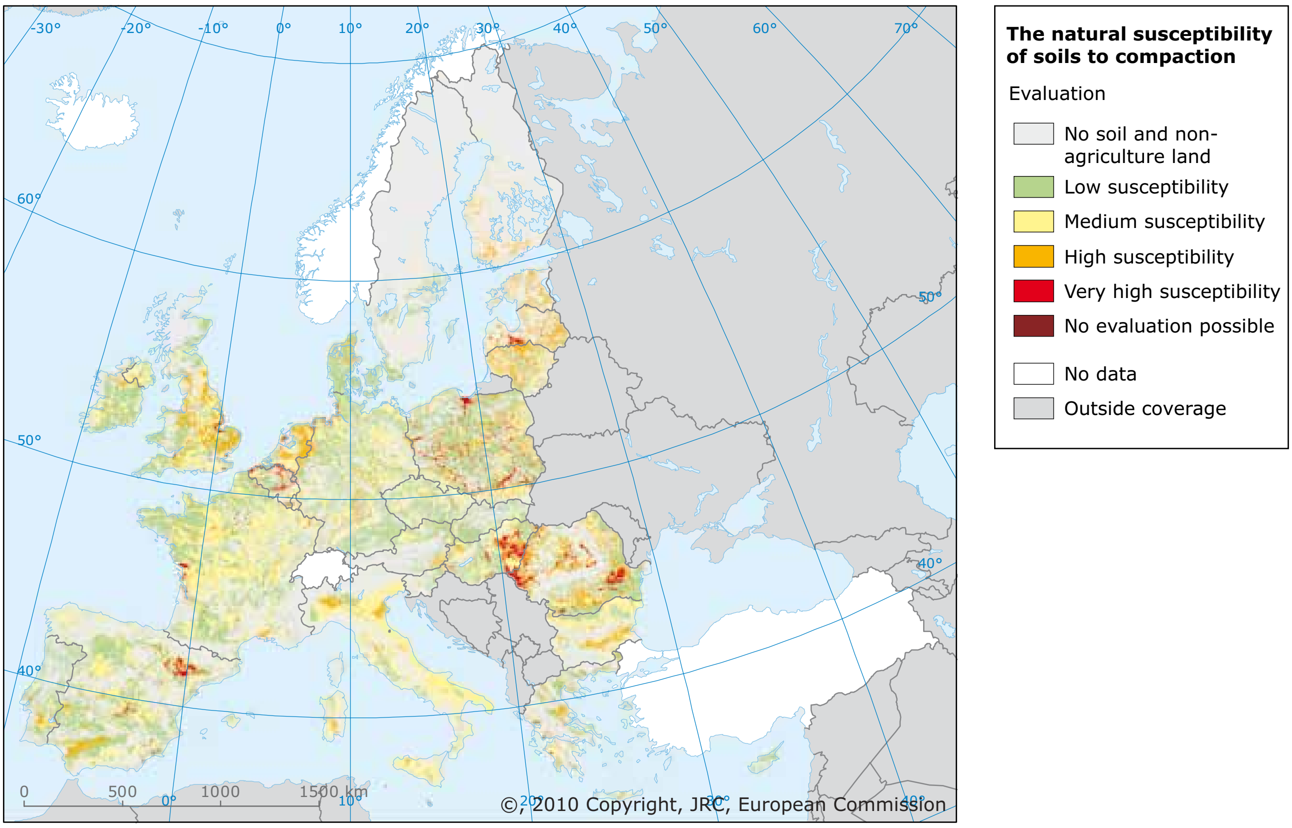
Source: JRC.

Photo 2.2: Soil erosion by rill development on an agricultural field 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

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.

- **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 (EEA, 2003; Lal, 1994). 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 move much more than 10 tonnes of soil 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}).

Map 2.5 The natural susceptibility of soils to compaction



Note: This map shows the natural susceptibility of agricultural soils to compaction based on soil properties and water regime. Susceptibility to compaction does not mean that a soil is compacted. It is the likelihood of compaction occurring if subjected to factors that are known to cause compaction.

Source: JRC.

- **Trends in erosion**: 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 land use assessment (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 (e.g. droughts may remove protective plant cover, more intense rainfall events leading to the physical displacement of soil particles) may well result in increased erosion.

Soil compaction occurs when soil is subjected to pressure from the use of heavy machinery or dense stocking with grazing animals, especially under wet conditions [11].

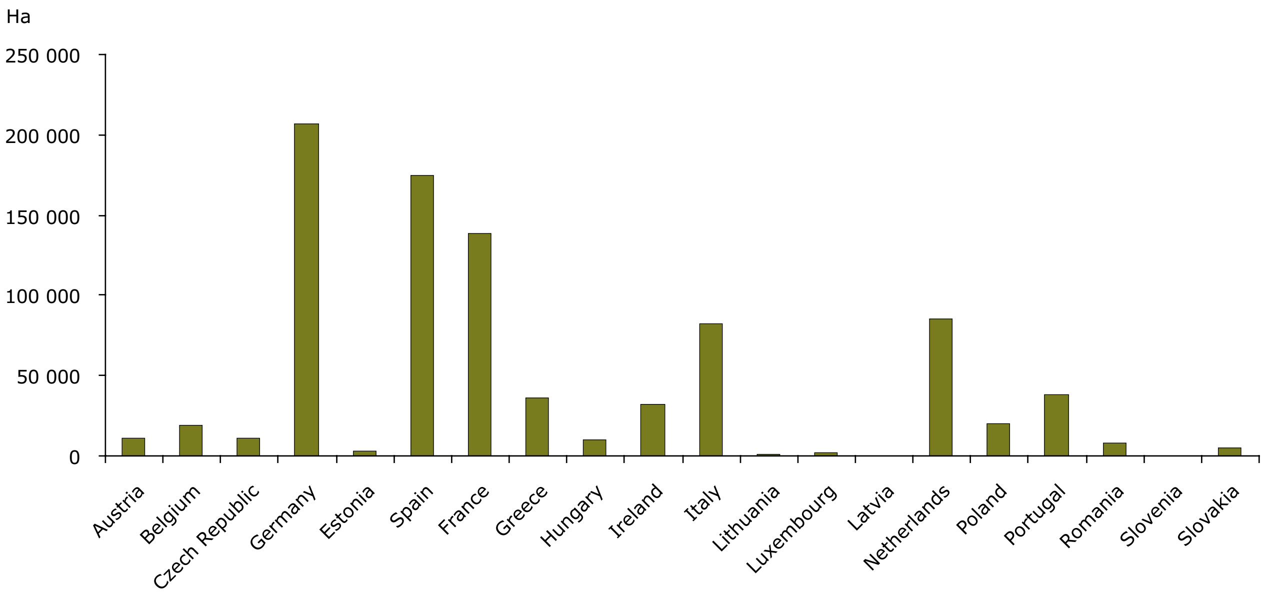
- **State of soil compaction:** Estimates of the area at risk of soil compaction vary. Some researchers classify around 36 % of European subsoils as having high or very high susceptibility to compaction (Van Camp et al., 2004). Other sources report that 32 % of soils are highly vulnerable and 18 % moderately 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**: Soil compaction is truly a hidden problem. 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 & Schjønning, 2004). In recent years, arable farming machinery has improved and tyre inflation pressures have been lowered to minimize compaction, but overall the problem remains.

Soil sealing happens when agricultural, forest or other rural land is taken into the built environment. Sealing also occurs within existing urban areas through construction on residual inner-city green zones.

- **State of soil sealing**: An assessment of the Corine land cover 2006 database shows that around 4 % of agricultural or other non-developed land is built on. This normally includes the removal of top soil layers

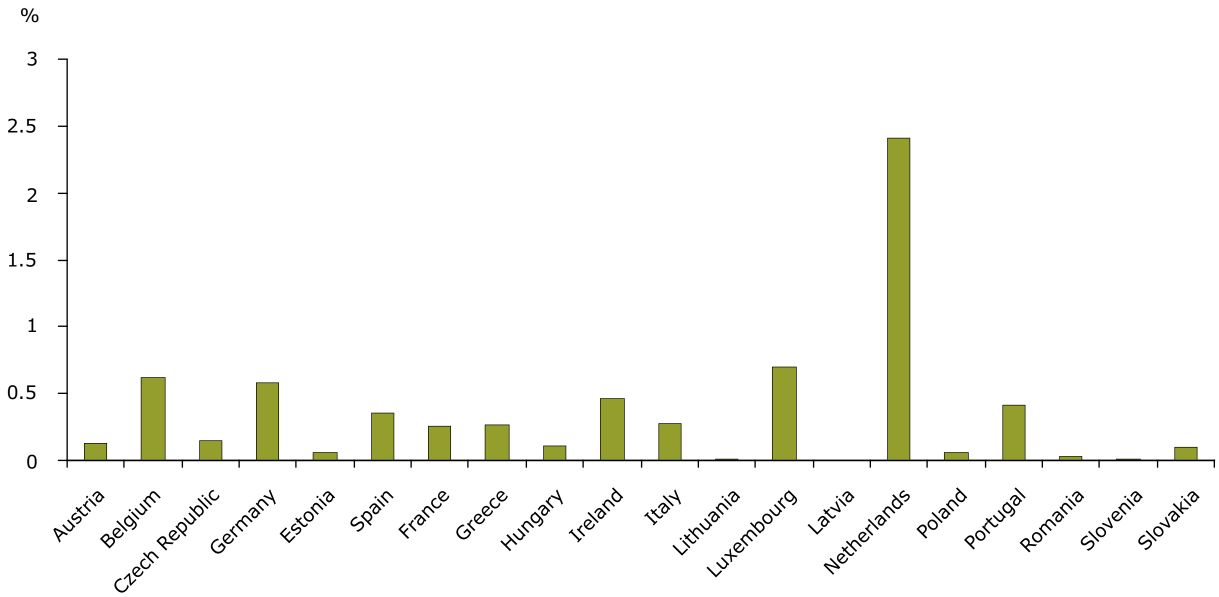
Figure 2.1 Losses of agricultural areas to urbanisation



Note: Comparison of Corine land cover data for 1990 and 2000 shows an estimated loss of 970 000 ha of agricultural land for 20 EU Member States in this ten year period due to urbanisation. 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 land use assessment (EEA, 2010b).

Source: JRC.

Figure 2.2 Relative losses of agricultural areas to urbanisation



Note: Comparison of Corine land cover data for 1990 and 2000 shows an estimated loss of 970 000 ha of agricultural land for 20 EU Member States in this ten year period due to urbanisation. 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 land use assessment (EEA, 2010b).

Source: JRC.

and leads to the loss of important soil functions, such as food production or water storage. On average, built-up and other man-made areas take up 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).

- **Trends in soil sealing**: Analysis carried out by the JRC showed that during 1990–2000, the sealed area in the EU-15 increased by 6 %, and productive soil continues to be lost to urban sprawl and transport infrastructures. Huber et al. (2008) provides an interesting insight into the development of baselines and thresholds to monitor soil sealing (see SOER 2010 Assessment on Land use for additional details on urbanisation).

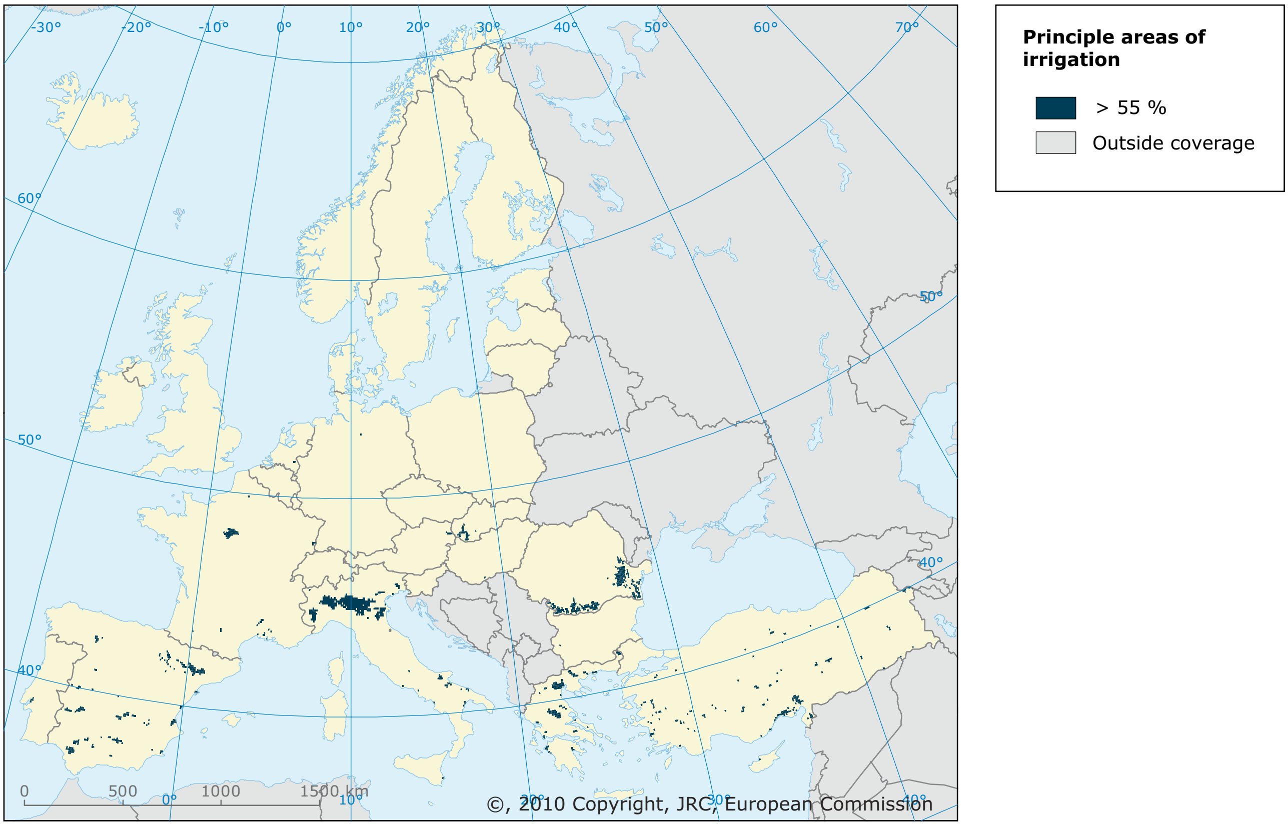
Salt accumulation in soil, commonly referred to as salinisation, is a world-wide degradation process. While naturally saline soils exist in certain parts of Europe, the main concern is the increase in salt content in the soils resulting from human interventions such as inappropriate irrigation practices, use of salt-rich irrigation water and/or poor drainage conditions. Locally, the use of salt for de-icing can be an issue. 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 precious, 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 and Slovakia.

- **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.

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

Map 2.6 Principle areas of irrigation



Note: Map of irrigation intensity as % 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 colours areas indicate the main areas of irrigation across Europe, zones that are vulnerable to the accumulation of salts in the soil.

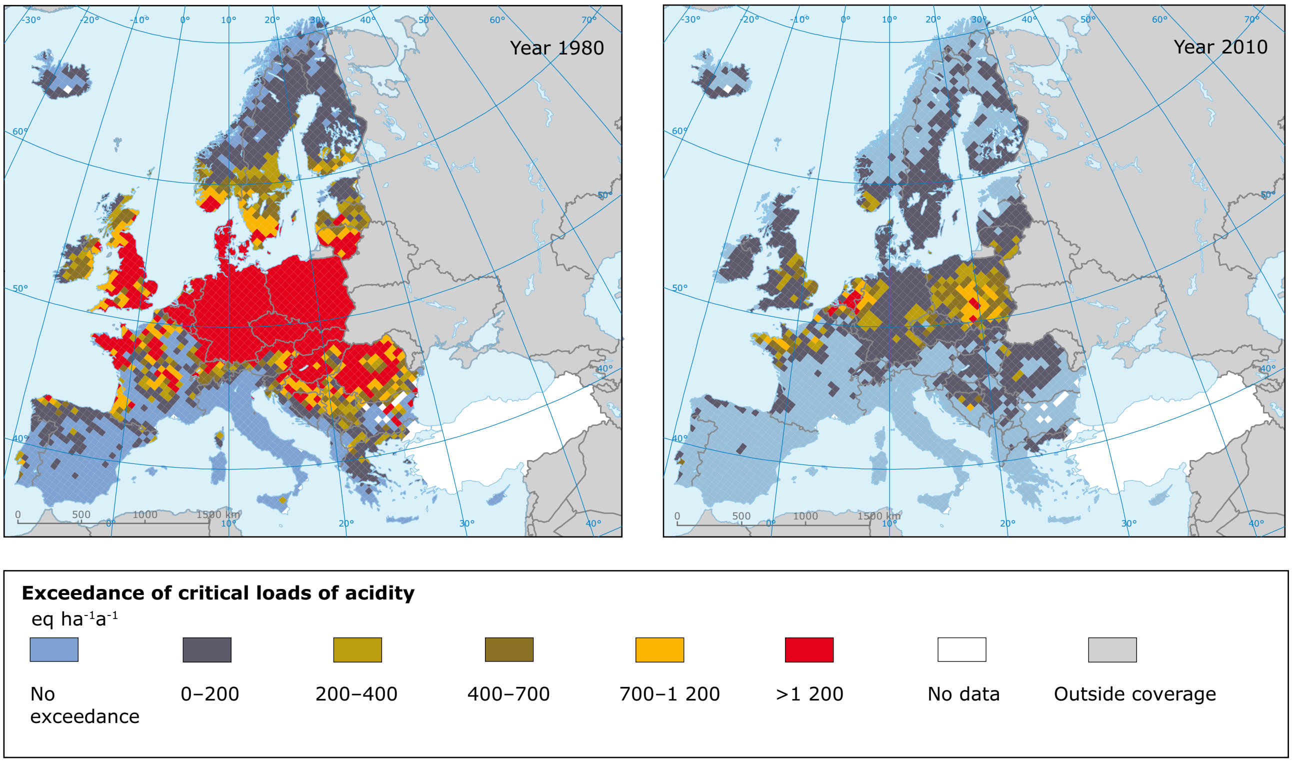
Source: FAO/AQUASTAT; Mulligan et al., 2006, map produced by JRC.

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). 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.

- **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 has 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 ser for the year 2010 has strictly speaking not been met, the improvements are considerable (see the SOER 2010 air pollution assessment (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, 2010a). 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).

Map 2.7 Exceedance of critital loads of acidity



Note: 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 with exceedances of critical loads of acidity (i.e. higher than 1 200 equivalent ha^{-1} year^{-1}, shaded red) cover large parts of Europe. By 2010, the areas where critical loads are being exceeded have shrunk significantly campared to 1980. 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 2010.

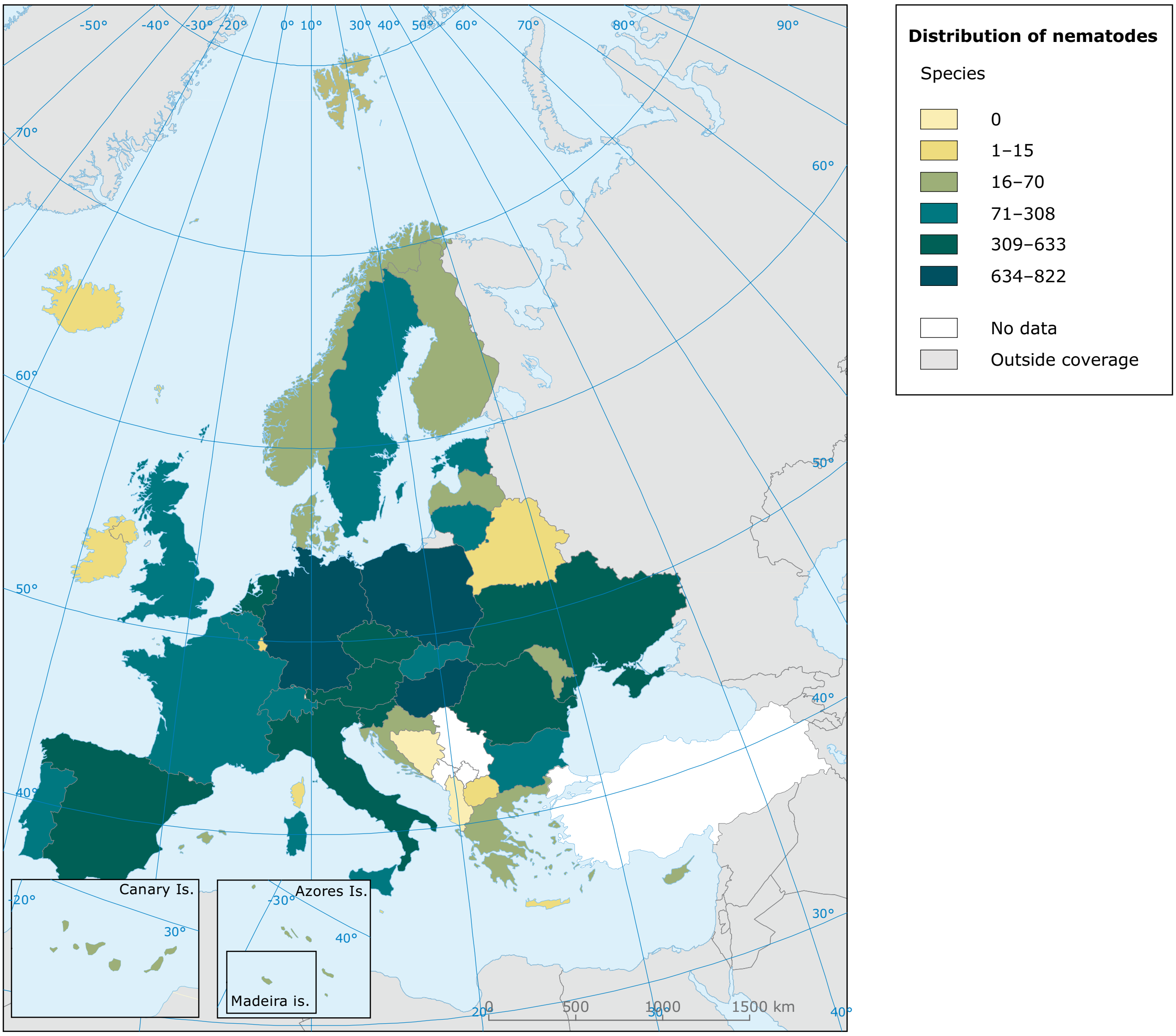
- **Trends in acidification:** As a result of regulation and improved practices, emissions of acidifying pollutants, particularly of SO_2, have fallen in recent years (see the SOER 2010 air pollution assessment, EEA, 2010c). A number of local and regional studies have shown that the impact of emissions reduction schemes in many parts of the United Kingdom, Germany and Scandinavia is especially evident with acid levels declining, rapidly in some parts, or are at least stabilising (Ruoho-Airola et al., 1998; Fowler et al., 2007; Kowalik et al., 2007; Carey et al., 2008, EEA 2010). 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.

Soil biodiversity: 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 water storage and transfer in soil (Lavelle and Spain, 2001). Soil biodiversity is generally defined as the variability of living organisms in soil and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems (UN, 1992).

- **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. 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. Recent analysis 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 % on this area (Jeffery et al., 2010).

Desertification: Prolonged droughts and more irregular precipitation, combined with unsustainable use of water

Map 2.8 Distribution of nematodes



Note: 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).

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 'Desertification, Land Degradation and Drought'. This reflects the widespread endorsement of the Convention also by countries that do not have drylands within their national territories. Within the EU, the following Member States consider themselves affected by desertification and are included in the Annex V of the UNCCD: Cyprus, Greece, Hungary, Italy, Latvia, Malta, Portugal, Slovakia, Slovenia and Spain (UN, 2001).

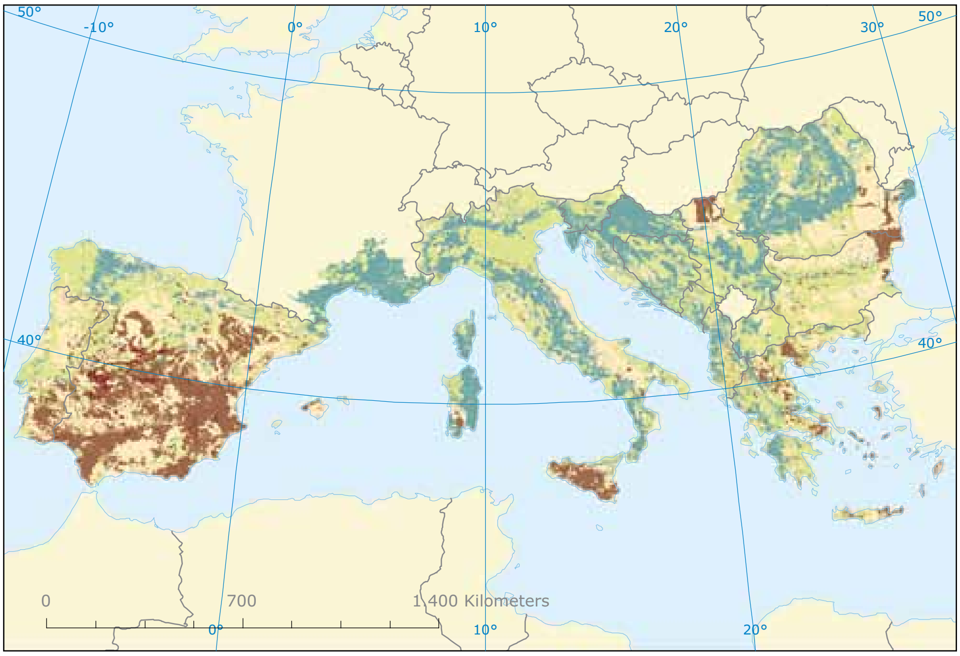
- **State of desertification:** The DISMED assessment (Domingues and Fons-Esteve, 2008) has shown that sensitivity to desertification and drought is lower in Europe than in neighbouring regions. The situation is most serious in southern Portugal, much of Spain, Sicily, south-eastern Greece and the areas 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 desertication, 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 through 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).

Landslides are the gravitational movement of a mass of rock, earth or debris down a slope (Cruden, 1991) [16].

- **State of landslides:** There are no data on the total area affected in Europe. 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 film of a major landslide in Calabria, Italy, February 2010]. The development and harmonisation of national landslide inventories should be a priority to serve

Map 2.9 Sensitivity to desertification



Index of sensitivity to desertification (SDI), 2008

< 1.2	Non affected areas or very low sensitivity to desertification
1.2–1.3	Low sensitivity areas to desertification
1.3–1.4	Medium sensitivity areas to desertification
1.4–1.6	Sensitive areas to desertification
> 1.6	Very sensitive areas to dersertification

Note: 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 and Fons-Esteve, 2008.

as a database for research into causes and potential remedial action.

Many countries are creating comprehensive nationwide landslide inventory databases. So far European national databases contain more than 600 000 recorded events but the true number of landslides in each country is certainly much higher: Italy (> 485 000), Austria (> 25 000), Norway (> 19 500), the United Kingdom (> 14 000), Slovenia (> 6 600), Iceland (> 5 000), Croatia (> 1 500) and Bosnia and Herzegovina (> 1 500) (JRC 2010b). Estimates of the total affected area have been made for Italy (7 %), Slovakia (3.7 %) and Switzerland (8 %). 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.

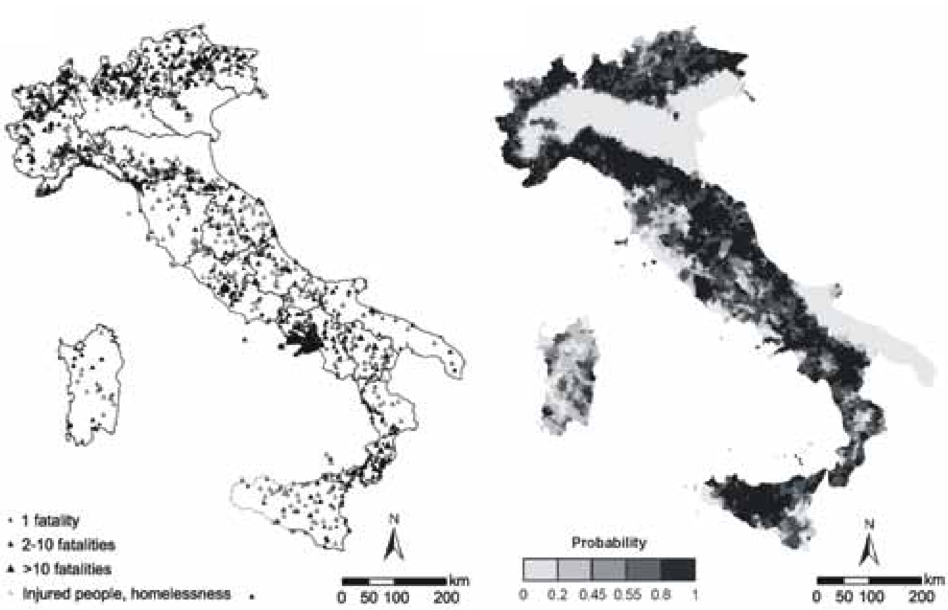
- **Trends in landslides:** While changes in land use, land cover and climate (higher and more intense rainfall patterns) will have an impact on landslides there are no pan-European data on trends in landslide distribution and impact. The national inventories described above will eventually provide the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

Photo 2.3 Landslide scar in the Veneto Italy.

Soil contamination: It is important to distinguish between local soil contamination (the result of intensive industrial activities or waste disposal [18]) and diffuse soil contamination covering large areas [19] (see also the SOER 2010 Consumption and the environment assessment (EEA, 2010d)).

- **State of soil contamination:** It is difficult to quantify the real extent of local soil contamination as many

Map 2.10 Landslides in Italy



Note: Left map: Distribution of landslides in Italy with human consequences from AD 1300 to 2002. The size of the symbol indicates the intensity of the event; right map: Landslide susceptibility map of Italy.

Source: Left map: Guzzetti et al., 2005; right map: Günther et al., 2008.

European countries lack comprehensive inventories together with a lack of EU legislation obliging Member States to identify contaminated sites (the Directive on the management of waste from extractive industries (EC, 2006a) is an exception). 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.

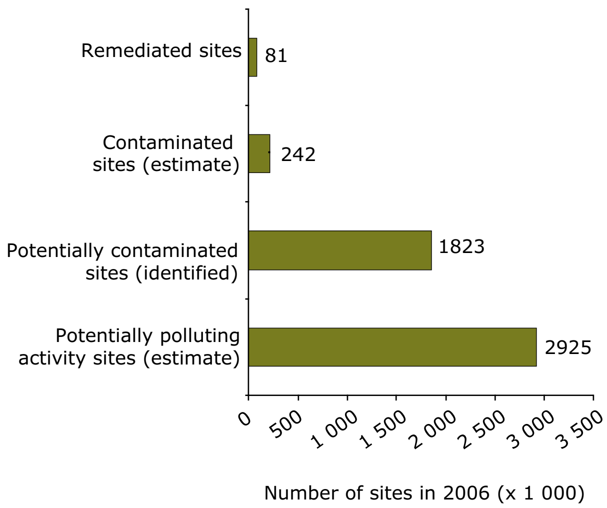
Data on diffuse contamination across Europe is even more limited than that for local contamination as there are no harmonised requirements to collect information. Rodriguez Lado et al. (2008) attempted to map the concentrations of eight heavy metals based on samples from the Forum of European Geological Surveys Geochemical database of 26 European countries, but noted mixed accuracies during the validation phase. Bouraoui et al. (2009) modelled fertilizer 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 without changes in legislation, 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 2.3). Around 80 000 sites have already been treated. In recent years, many industrial plants have attempt to change their production processes to produce less waste while 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. The collapse of the dam at the aluminium plant in Hungary in October 2010 shows 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 air pollution assessment (EEA, 2010c).

While reports show that fertiliser sales have remained stable or fallen in EU-15 countries, consumption in Europe as a whole has continued to grow steadily during recent years, although it is too early to detect any impact of the recent economic crises (Eurostat, 2010a; FAO, 2008). However, a number of recent indicators (e.g. IRENA Gross Nitrogen Balance; EEA 2005a) and reports (EC, 2010) have noted that nitrate levels in water bodies across Europe have fallen markedly (in up to 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 fertilizer 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 followed to reduce the risk of pollution of water courses from manure applications.

Figure 2.3 Contaminated sites in Europe, 2006



Note: The graphs 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.

3 Impacts

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 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 (approximately 3.4 % soil organic matter) 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 (Verheijen et al., 2005; Loveland and Webb, 2003; Arrouays et al., 2001, 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 about 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 — a sink — in soils under grassland and forest (from 0–100 million tonnes of carbon per year) and 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, 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 nevertheless potentially very damaging in the long run.

- **Compaction**: Compaction can lead to a decrease in a number of key soil functions by reducing the pore space between soil particles, increasing bulk density and reducing or totally destroying the soil's absorptive capacity. The reduced infiltration increases surface runoff and leads to more erosion. Heavy loads on the soil surface, that cause compaction in the subsoil are cumulative and in time the bulk density of the subsoil will increase significantly. Compaction results in a greatly reduced rootability for crops 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, once subsoil compaction occurs, it 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, the compaction is virtually irreversible (Ruser et al., 2006).

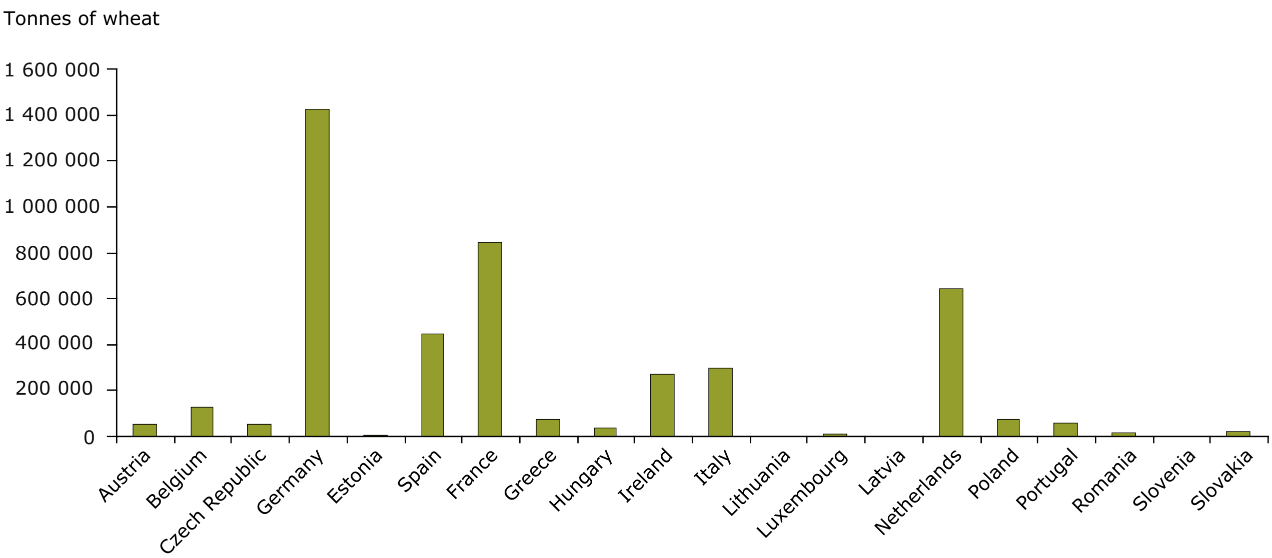
- **Soil sealing:** Soil sealing causes adverse effects on, or complete loss of, soil functions and prevents soil from fulfilling important ecological functions. Fluxes of gas, water and energy are reduced, affecting, for example, soil biodiversity. The water retention capacity and groundwater recharge 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. Soil sealing appears to be almost irreversible and may result in an unnecessary loss of good quality soil.

  Soil sealing can lead to the contamination of soil and groundwater sources because of higher volumes of unfiltered runoff water from housing, roads 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

Photo 3.1: Soil sealed by road construction
© Otto Spaargaren

Figure 3.1 Annual impact of soil losses due to urbanisation



Note: 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 4.4 million of tonnes of wheat.

Source: JRC: Gardi et al., 2009.

of floodplains, in excess of national health thresholds (Umlauf et al., 2005).

- **Salinisation:** Elevated salt levels in soil limit 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 as flood, 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:** Decline in soil biodiversity as a result of 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.

- **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 valley inundation 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 mainly integrating landslide susceptibility/hazard and risk mapping in land-use planning and establishing early warning systems for active landslides (Hervás, 2003).

A positive impact of landslides is that they are a major source of sediment to 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 important problem as the contamination is practically irreversible. Contamination can affect human health either through direct contact or by ingestion through the food chain (also through contaminated water).

  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 decline in general health (UKEA, 2009). The concentrations might reflect the natural condition of the soil or the consequences of pollution, particularly associated with 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) estimates:

  - 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 run off and landslides, increased health-care 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.

4 Outlook 2020

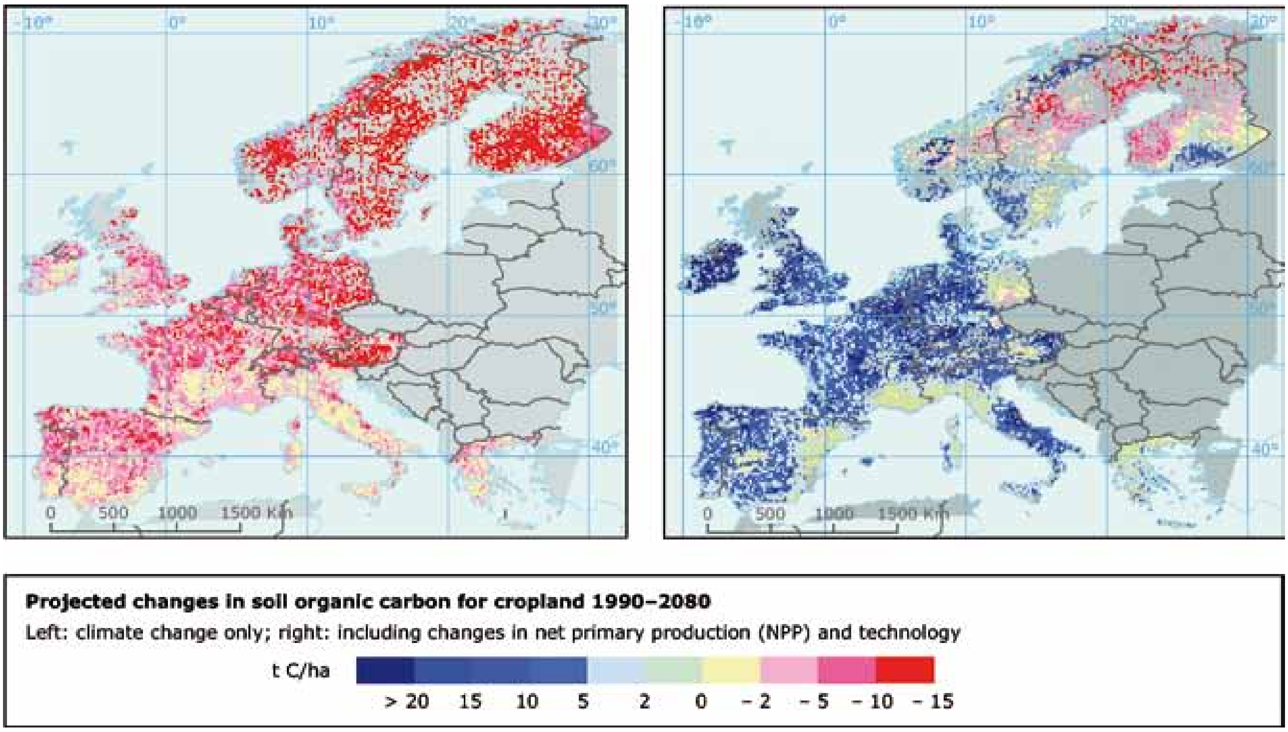
The inherent complexity and spatial variability of soil makes the evaluation of the impact of any change difficult. Transformations of features such as texture and mineralogical composition will only occur over geological time spans while properties such as pH, organic matter content or microbial activity 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.

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. 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

Map 4.1 Projected changes in soil organic carbon for cropland 1990–2050



Note: 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 (development of higher yielding varieties through improved stress resistance and/or yield potential) that result in yield increases.

Source: Smith et al., 2005.

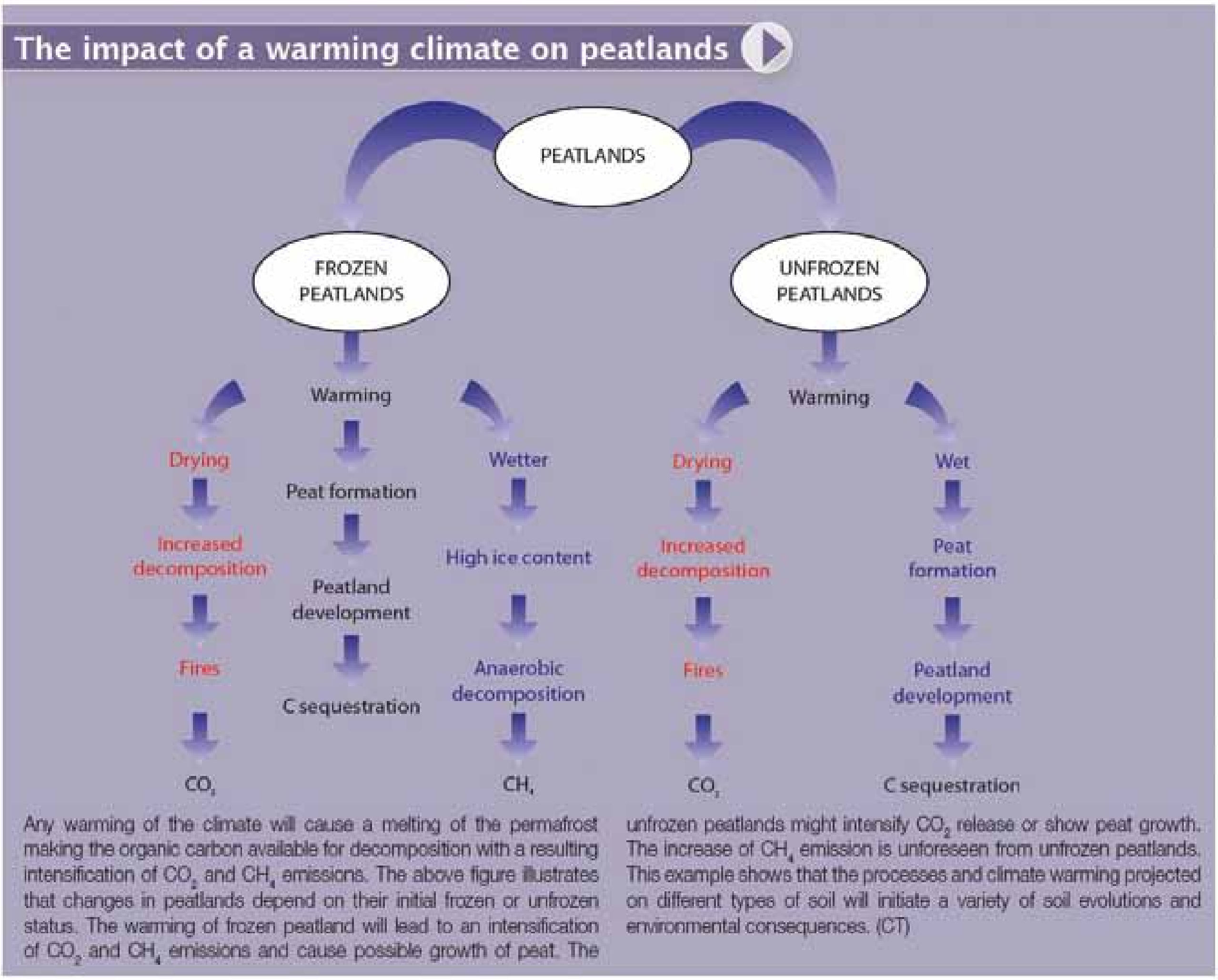
accelerate decay rates, leading to an intensification of CO_2 and CH_4 emissions from soil to the atmosphere. Soils in the EU contain around 75 billion tonnes of carbon or 7 % of the total global carbon budget (IPCC, 2000a). This is a huge amount compared with the 2 billion tonnes of carbon emitted annually 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. Conversely, the warmer and more humid conditions in Fennoscandinavia could lead to more vegetation growth, increasing levels of soil biodiversity and an enhancement of SOC levels.

The following figure (Jones et al., 2010) illustrates how local conditions and climate will determine the carbon fluxes for peatlands.

By absorbing up to twenty times its weight in water, increased SOM can contribute to the mitigation of flooding

Figure 4.1 The impact of a warming climate on petlands



Source: Jones et al., 2010.

following extreme rainfall events while storing water in the event of more frequent and severe droughts.

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.

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 depend on world markets and conclude that beef and dairy herds are most likely to decrease which 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 coming 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.

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 reflect the discussions on soil organic matter. IPCC scenarios showing 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 tremendous 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 reflects 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.

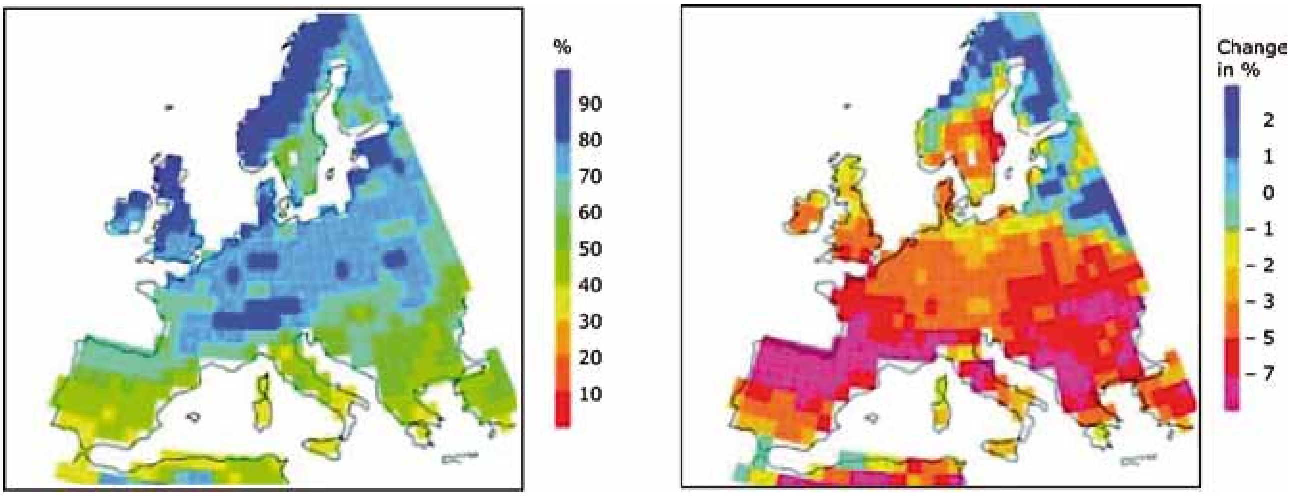
Several studies have been conducted to model the effects of climate change on soil erosion. Kirkby et al. (2004) describes a non-linear spatial and temporal response to climate change, with relatively large increases in erosion during wet years compared to dry years, and sporadic increases locally. Nearing 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 Soil water retention

Water retention is a major hydraulic property of soils that governs soil functioning in ecosystems and greatly affects soil management. 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. agriculture).

Variations in SOM levels to 2020 have been described in Secion 4.1. For these discussions 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 holding capacity of soil and hence its usability. Rawls et al. (2003) showed that at low SOM levels, any increase in SOM

Map 4.2 **Summer soil moisture conditions over Europe as for the period 1961–1990 (left) and projected changes for 2070–2080 (right)**



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

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 and OM type.

Increased temperatures across Europe will result in changes in evapotranspiration (the sum of evaporation from the Earth's land surface and loss of water from plants to the atmosphere) and soil moisture. Models show that the impact of global warming on evapotranspiration shows a sharp transition from slight increases (0.1–0.5 mm day^{-1}) 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^{-1}.

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 and desertification.

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 2010). Recovery from acid deposition is characterised by decreased concentrations of sulphate, nitrate and aluminum in soils. An increase in pH and acid-neutralizing 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 developing clean and economically sustainable energy systems that reduce our reliance on fossil fuels. One such avenue is biofuels: converting sugars from bioenergy crops into fuel or converting biomass to liquid fuels such as ethanol and biodiesel or gaseous fuels such as methane. Biofuel production therefore involves the cultivation of suitable crops. There are concerns that increasing biofuel production may lead to inappropriate land management practices and increased levels of land 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 in 2020. This area will derive from existing agricultural land and obligatory set aside to which could be added severely degraded and contaminated land (EC, 2007). Organic matter depletion and loss of essential plant nutrients from soils leads 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).

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). 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 degradation, ensuring that EU soils stay healthy for future generations and remain capable of supporting the ecosystems on which our economic activities and our wellbeing 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 abundantly shown in Chapter 2, soil degradation in the EU is continuing to occur and is actually worsening for certain processes in some parts of Europe. This is a clear demonstration that existing policies and legislation, at EU as much as at national level, have not been sufficient. Action is required at EU level, both because of the crucial functions soil performs for society and European ecosystems, and because of legislative differences between Member States in dealing (or not dealing) with soil problems that may distort competition within the single market, hinder the action of the more pro-active Member States, and prevent the Union from meeting its 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 protection because of its links to other environmental goals (e.g. the Water Framework Directive).

The legislative proposal has 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 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 vulnerable 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 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 EEA and the Commission to fulfil their information needs. The establishment and the evaluation of harmonised databases would enable a better identification of the necessary soil protection measures.

5.2 The role of the Common Agricultural Policy in promoting sound soil/land management practices

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 albeit it is not known which land use would have existed if marginal areas had been abandoned or converted to other uses. The cross-compliance requirement to sustain levels of permanent pasture (within certain margins) could maintain soil structure and organic matter levels in soil, and so soil carbon. In contrast, abolition of permanent set-aside land leads to negative impacts on soils. Following the Health Check of the CAP in 2009, the requirement for arable farmers to leave 10 % of their land fallow was abolished. As this loosening of regulations will allow land to go back into production under tillage crops to maximise production, the change 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, increase nutrient soil nutrient levels through natural fixation by plants and crop rotation). Conservation agriculture comprises a combination of practices with 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 through 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.

5.3 Rural development, sustainable agriculture and soil conservation

Agriculture occupies a substantial proportion of European land, and consequently plays an important role in maintaining natural resources and cultural landscapes. Unsustainable farming practices and land use, including mismanaged intensification and land abandonment, have an adverse impact on natural resources. 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 concluded that there is a range of measures within the current rural development policy (EAFRD) 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. 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.

5.4 Mitigation and adaptation to climate change

The European Commission's recent 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. As agricultural soils are concerned, 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 the 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).

5.5 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.

5.6 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 such as from the European Land and Soil Alliance (ELSA) is aiming to improve this situation through targeted educational measures for school curriculums, university courses, policymakers and the general public.

Glossary/supporting information

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 (both 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 life-span of a human being, soil loss is not recoverable which means that we must regard soil as a non-renewable resource.

2. **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.

3. **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. Although people have become increasingly aware of the environmental impacts of peat cuttings and are looking for alternative, 'peat-friendly' composts.

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 a percentage by weight (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).

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 geologic 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 one t ha^{-1} yr^{-1} for mineral soils (see ENVASSO Report — Huber et al., 2008), although under specific conditions (e.g. extremely high precipitation combined with high temperatures) actual soil formation rates can be substantially greater. However, it would 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 19 November 2010).

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 19 November 2010).

11. **Compaction:** Topsoil compaction considers 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 tractor wheels driving directly on 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, the 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:** While the acidification of soils can be a natural, long-term process (e.g. plants take base cations from the soil, humic acids from litter can mobilise base elements, leaching, harvesting of high yield crops), acid deposition accelerates the process. Soils will acidify if there is (i) a source of H^+ ions to replace base cations removed by ion exchange processes (ii) a means of removing the displaced base cations, achieved by a mobile anion such as sulphate (SO_4^{2}) or nitrate (NO_3^-). 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' H^+, aluminium, iron and manganese irons 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 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, A.M. and van Gestel, G.H., 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} a^{-1}), is the base cation (BC) to aluminum (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, man-made 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. **Video showing graphic examples of landslides in Calabria, Italy — February 2010.** www.youtube.com/watch?v=BmO_YLVjMCY (accessed 19 November 2010).

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 is 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 19 November 2010).

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 effectiveness and efficiency of instruments for soil protection in Europe, opportunities and critical issues linked to the adoption of conservation practices. http://soco.jrc.ec.europa.eu/index.html (accessed 19 November 2010).

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