# Organic Matter in the soils of Europe: Present status and future trends

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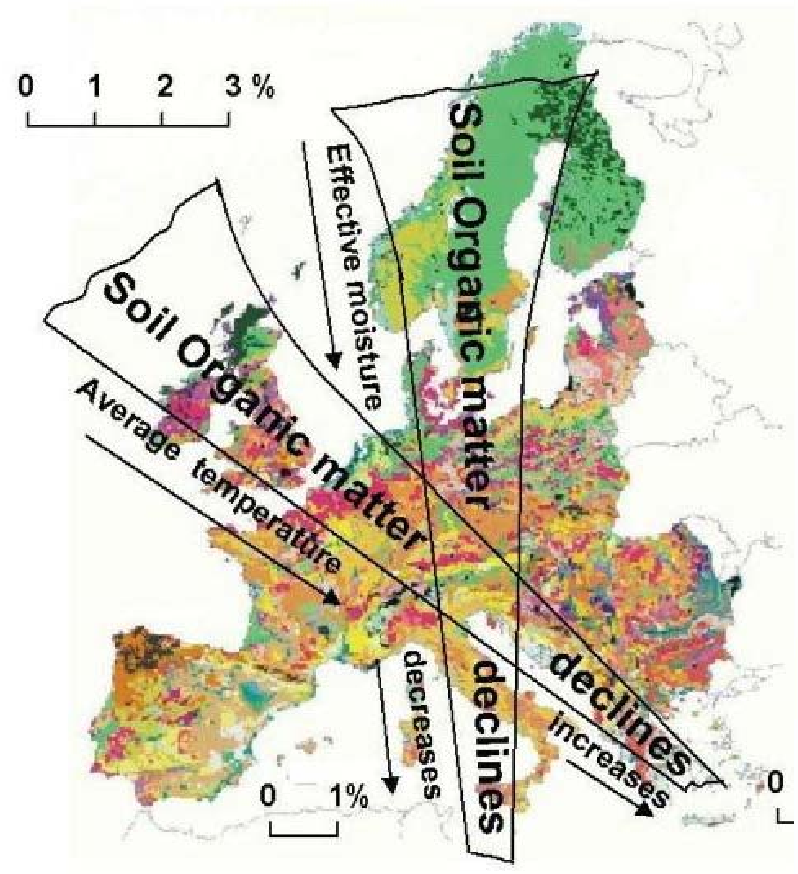

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# Contents

# Abstract

The need for accurate information on the organic matter (OM) content in soils at European, National or Regional level has been increasing steadily over the past few years. This is a result of increasing concern about environmental problems such as soil degradation, desertification (CEC, 1992; UNEP, 1991), erosion and, at the worldwide level, the impact of climate change. There is some evidence to suggest that the OM content of soils in Europe is decreasing, in some cases at an alarming rate, and yet OM is vital to sustain many soil functions. For example, a decline in OM content is accompanied by a decrease in fertility and loss of structure that together exacerbate overall soil degradation. There are many factors responsible for the decline in soil OM and many of them stem from human activity, for example:

- Conversion of grassland, forests and natural vegetation to arable land;
- Deep ploughing of arable soils causing rapid mineralisation of organic matter, particularly Humus;
- Overgrazing;
- Soil erosion;
- Forest fires.

The main objective at present is to identify and secure an existing information base for organic matter (OM) contents of European soils at time $T_0$, i.e. to define a ‘background or reference level’. Effectively this means compiling and analysing data on the organic carbon (OC) content because in most cases this is the parameter that is measured. The next objective is to establish the future trend in soil OM contents with a view to developing more sustainable systems of land management and avoiding or reducing further losses. This paper attempts to summarize briefly existing knowledge about the OM content in the soils at European level. Same examples of the knowledge base, the improvements that are needed and possible trends in soil OM content at regional level are given.

# 1 Introduction

Over the centuries, soil organic matter (OM) has come to be considered as the *elixir of plant life*. At a very early stage in history, man discovered that soil colour is closely correlated with organic matter that derives mainly from decaying plant materials. Soils high in organic matter were also found to be productive, both for crop production and for providing good pasture for grazing animals.

To ensure sustainable management of the land, therefore, it is imperative that organic matter in the soil is maintained and sustained at satisfactory levels. A decrease in organic matter content is an indicator of a lowered quality in most soils. This is because soil organic matter is extremely important in all soil processes.

A high content of organic matter in the soil is not just responsible for ensuring stable crop production but also for maintaining the soil in good condition. Structure, water capacity, pH, soil microorganism, drainage and other parameters of the soil are conditioned by the content of OM. Loss of OM from the soil means soil degradation. For example, heavy textured soils respond by slaking, swelling, cracking, and mellowing, when they are wetted, and, because of this, surface seals or crusts develop encouraging soil erosion on slopes. Sandy soils lose their cohesion and are easily removed as single grains by water or wind.

Soil organic matter is extremely important in all soil processes. It is essentially derived from residual plant and animal material, synthesised by microbes and decomposed under the influence of temperature, moisture and ambient soil conditions.

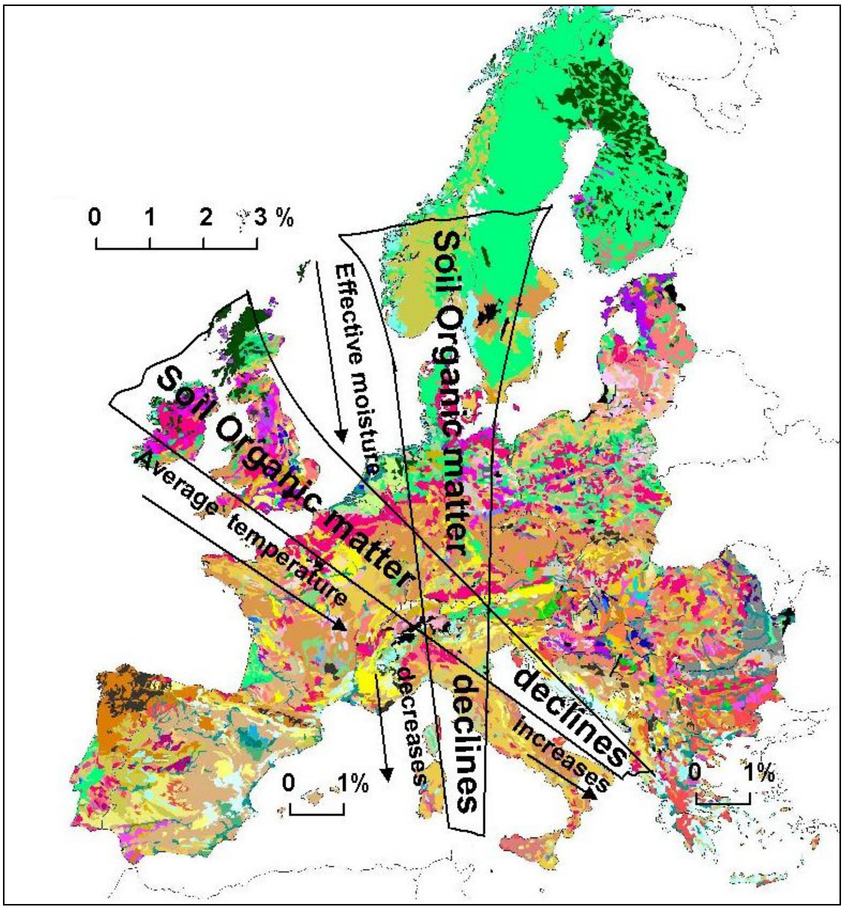


***Figure 1 Influence of temperature and moisture on soil organic matter content in Europe***

There are two groups of factors that influence inherent organic matter content: natural factors (climate, soil parent material, land cover and/or vegetation and topography), and human-induced factors (land use, management and degradation). Heterogeneity is the rule for the organic matter content of mineral soils.

Within belts of uniform moisture conditions and comparable vegetation, the average total organic matter and nitrogen content can increase from two to three times for each $10^0$ C fall in mean temperature. In general, under comparable conditions, the nitrogen and organic matter content increase as the effective moisture becomes greater. Figure 1 is a diagrammatic attempt to show these influences geographically.

## 1.1 Effect of cultivation

Cultivation can have a significant effect on the organic matter content of the soil. During field operations, fresh topsoil becomes exposed to rapid drying on the surface. Organic compounds are released to the atmosphere as a result of the breakdown of soil aggregates that are bound together by humic materials. Unless the organic matter is quickly replenished, the system is in a state of degradation leading eventually to un-sustainability (World Bank, 1993). The annual rate of loss of organic matter can vary greatly, depending on cultivation practices, the type of plant/crop cover, drainage status of the soil and weather conditions (Waters and Oades, 1991).

When natural or semi-natural habitats are cultivated, new and usually lower levels of organic matter and nitrogen are established. It is therefore normal to find much lower OM and nitrogen contents (by 30 to 60%) in cultivated soils compared to their undisturbed (or virgin) equivalents.

However, the fact that crop yields in areas long under cultivation have been maintained or raised does not mean that organic matter and nitrogen are being maintained at satisfactory levels.

Experiments conducted in the USA show a decline of up to 30% in organic matter content of soils that were cropped over a long period (Zdruli *et al.* 1999). This is confirmed by results from Rothamsted Experimental Station (Table 1) showing that very different forms of manuring and cropping have had a very large influence on the carbon and nitrogen contents but only a small influence on the C/N ratio (Russell, 1961, p277).

**Table 1 Carbon, nitrogen contents & C/N ratio of some Rothamsted soils**

| **Management/vegetation** | **% C** | **% N** | **C/N** |
|---|---|---|---|
| Old pasture (8-18cm) | 1.52 | 0.160 | 9.5 |
| Old woodland (13-18cm) | 2.38 | 0.250 | 9.5 |
| Broadbalk, after 50 years continuous wheat, 1893 | | | |
| **No manure since 1839 (0-23cm)** | **0.89** | **0.099** | **9.0** |
| Complete minerals and 185kg $(NH_4)_2SO_4$ most years since 1843 (0-23cm) | **1.10** | 0.12 | 9.0 |
| **14 tons of farmyard manure annually since 1843 (0-23cm)** | **2.23** | **0.22** | **10.1** |

It is not possible to maintain the organic matter and nitrogen of cultivated at ‘virgin’ levels and nor is it necessary to do so. However, a decline in organic matter content of 30 to 40% has serious implications for soil structure and fertility (Russell, 1961, p293). Such a decrease should not be allowed to continue otherwise a serious decrease in crop yield and loss of structural stability could result.

Zdruli et al (1995) point out that the rate of decrease of soil organic carbon (OC) due to drainage and cultivation in former swamp areas could be as high as 80 percent in just 38 years. In annual crop production, a decline can be halted by leaving crop residues on the soil surface and/or by adding organic manure. The removal of crop residues in dry ecosystems, which are inherently marginal, can cause such systems to be quickly transformed from a stage of fragility to one of total exhaustion and depletion.

## 2 Organic Matter Content in European Soils

In many areas of Europe, not only in the south, where soils have been intensively cultivated for a very long period, the decline in organic matter content is equivalent to a ‘mining’ operation. It may be possible to restore the organic matter to acceptable levels in some soils that have suffered serious depletion, but this will be a lengthy process.

To avoid further losses of organic matter (OM) from the soil, the first stage is to determine the amount of organic matter currently stored, identify the sources and discover the causes of any decrease. For policy making purposes, it is now vitally important to have an accurate picture of the OM content in European soils and understand the components of the systems of land management that have the greatest effect.

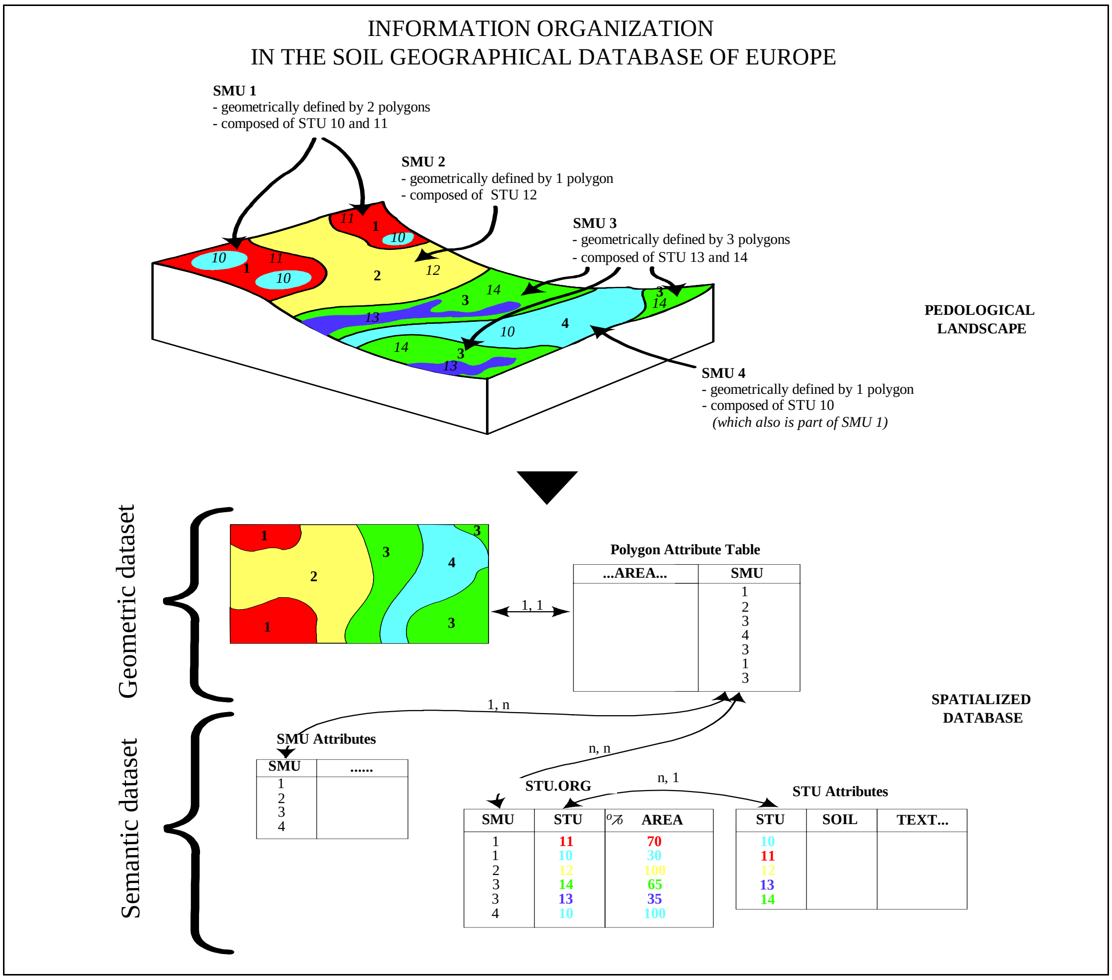


***Figure 2 Structure of the European Soil Database***

In most cases, organic matter (OM) in soil is measured as organic carbon (OC) and the values converted to organic matter content using a standard conversion ratio OC:OM of 1:1.7. This conversion is considered to be satisfactory for providing data on OM, given OC measurements, for input to the policy making process. However, in reality there is a serious lack of measured data on soil carbon and hence OM too. The most homogeneous and comprehensive data on organic matter (OM) content of soils at European level are those that can be derived from the European Soil Database at scale 1:1,000,000. The structure of this database is shown Figure 2.

## 2.1 Studies at European Level

There is a lack of reliable data on soil carbon in Europe. To correct this, the European Soil Bureau has been developing, in collaboration with the Member States, a soil profile analytical database (Madsen and Jones, 1995, 1998) containing data that can be related to the European Soil Geographical Database at 1,000,000 scale. The profile database contains some values for organic carbon in the topsoil (0-30cm) for the main soil map units (SMU) but these data are far from comprehensive and have poor replication. They do not give a complete or accurate coverage for the whole of Europe

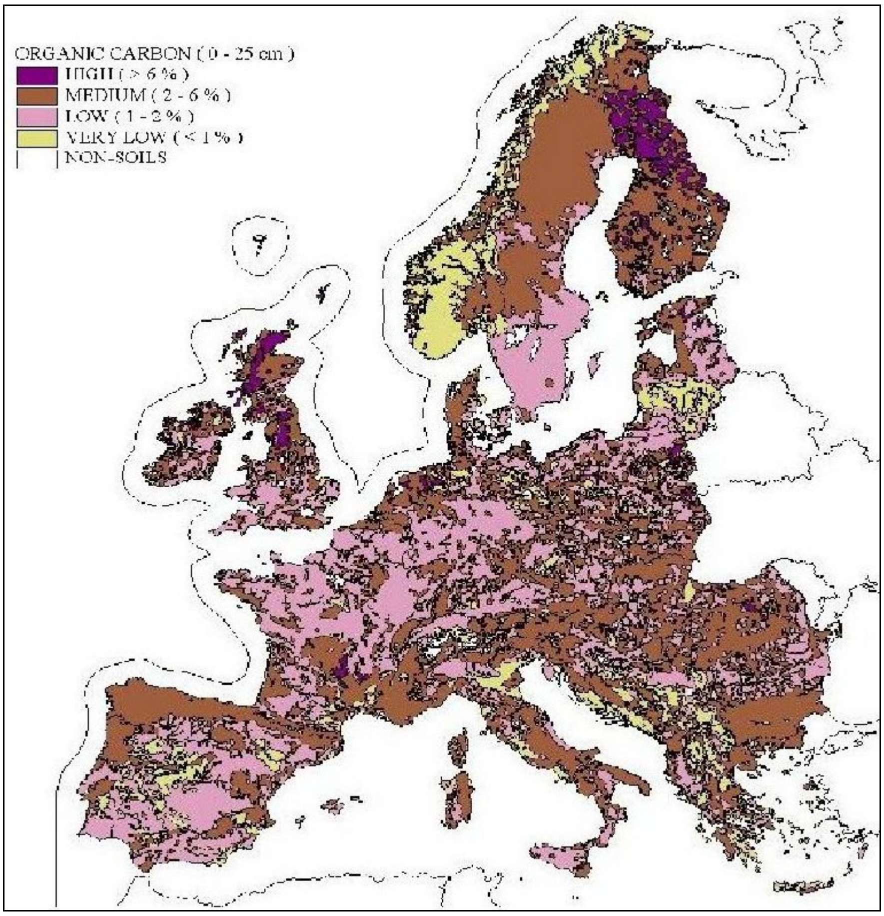


***Figure 3 Distribution of topsoil organic carbon through application of a pedotransfer rule to the European Soil Database***

Until a better soil profile database has been compiled, one alternative is the estimation of organic carbon from soil classification and climatic criteria. A pedotransfer rule has been developed to convert the 1:1,000,000 scale soil map units (SMU) into classes of organic carbon content (Van Ranst et al., 1995; Jones and Hollis, 1996; Daroussin and King, 1997). The rule estimates topsoil (0-30cm) organic carbon content (OC_TOP) from a combination of FAO soil name, topsoil textural class, regrouped land use class and accumulated mean temperature.

The results are output in four classes:

H(igh): > 6.0%
M(edium): 2.1-6.0%
L(ow): 1.1-2.0%
V(ery) L(ow): < 1.0%

Figure 3 shows the estimated organic carbon level in the topsoil (OC_TOP) derived from the European Soil Database using the pedotransfer rule. These estimates can only be considered as very approximate and are only suitable for use at the continental level. However, because the results are expressed as classes of OC it is difficult to establish the true OC content in European soils. For example, peat soils contain much more OC (>15%) than the lower limit of 6% of the highest class (OC>6%) estimated by the pedotransfer rule and therefore this analysis does not separate them from soils with less OC that fall into this class.

**Table 2 Organic carbon content of soils in Europe**

| **Hectares ha** | **OC class** | **OC content (%)** | **Area (%)** |
|---|---|---|---|
| **66,558,238** | **V** | **<1%** | **13** |
| **163,967,166** | **L** | **1-2%** | **32** |
| **232,325,106** | **M** | **2-6%** | **45** |
| **22,173,470** | **H** | **>6%** | **5** |

This analysis shows than 40% of European soils have an OC content in the class 2-6% and many of these soils are in agricultural use. Table 2 shows the proportion of Europe in the different classes of OC content.

## 2.2 Soil organic matter in southern Europe

In response to the concern about low organic matter levels in Mediterranean soils and to provide some guidance for policy makers, the European Soil Database was used to make preliminary estimates of the organic carbon contents of topsoils in southern Europe (Zdruli *et al.* 1999). However, the European pedotransfer rule has been found to give poor results in southern parts of the continent, where the criteria used do not relate well to soil organic carbon content. In an attempt to overcome this problem, the units (SMU) on the southern part of the European Soil Map were assigned to one of 2 classes of organic carbon (OC) - OC≤2% and OC>2% -using expert judgement.

The results (Figure 4) show that 74% of the land in southern Europe has a surface soil horizon (0-30cm) that contains less than 2% OC (3.4% OM). This is an important statistic and it is now clear that the decline in organic matter contents of many soils in Southern Europe, as a result of intensive cultivation, has now become a major process of land degradation.

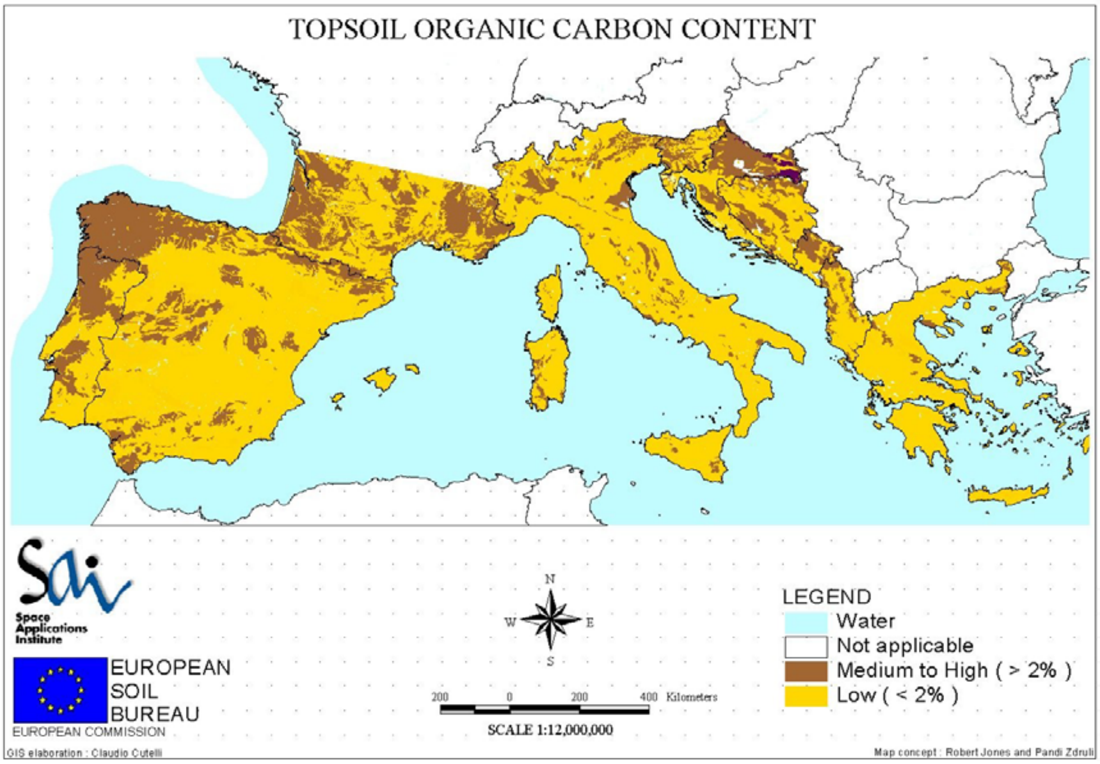


***Figure 4 Estimated Organic Carbon contents in the topsoils of Southern Europe***

Table 3 lists the proportion for the different countries in the region

**Table 3 Estimated Organic Carbon (OC) content in the topsoils of Southern Europe**

| | **Total land area** | **V low to Low** | **OC<=2%** | **Medium to High** | **OC>2%** |
|---|---|---|---|---|---|
| **Country** | **km2** | **Km2** | **%** | **km2** | **%** |
| Albania | 28,704,567 | 21,575,076 | 75.2 | 6,788,233 | 23.6 |
| Bosnia | 51,524,030 | 34,453,723 | 66.9 | 16,898,412 | 32.8 |
| Croatia | 56,191,096 | 28,030,731 | 49.9 | 26,903,652 | 47.9 |
| France (S of 45°N) | 196,550,777 | 116,603,968 | 59.3 | 78,371,704 | 39.9 |
| Greece | 133,007,789 | 126,841,043 | 95.4 | 4,868,798 | 3.7 |
| Italy | 300,453,890 | 259,601,949 | 86.4 | 37,341,722 | 12.4 |
| Montenegro | 13,792,171 | 7,012,719 | 50.8 | 6,531,899 | 47.4 |
| Portugal | 89,335,536 | 51,026,010 | 57.1 | 37,944,766 | 42.5 |
| Slovenia | 20,235,843 | 11,615,170 | 57.4 | 8,375,443 | 41.4 |
| Spain | 498,914,695 | 378,630,678 | 75.9 | 117,451,853 | 23.5 |
| **Southern Europe** | **1,388,710,394** | **1,035,391,069** | **74.6** | **341,476,480** | **24.6** |

## 2.3 Studies at national level

The following sections describe studies of soil carbon contents in Italy, UK and France.

### 2.3.1 Organic carbon stocks in Italy

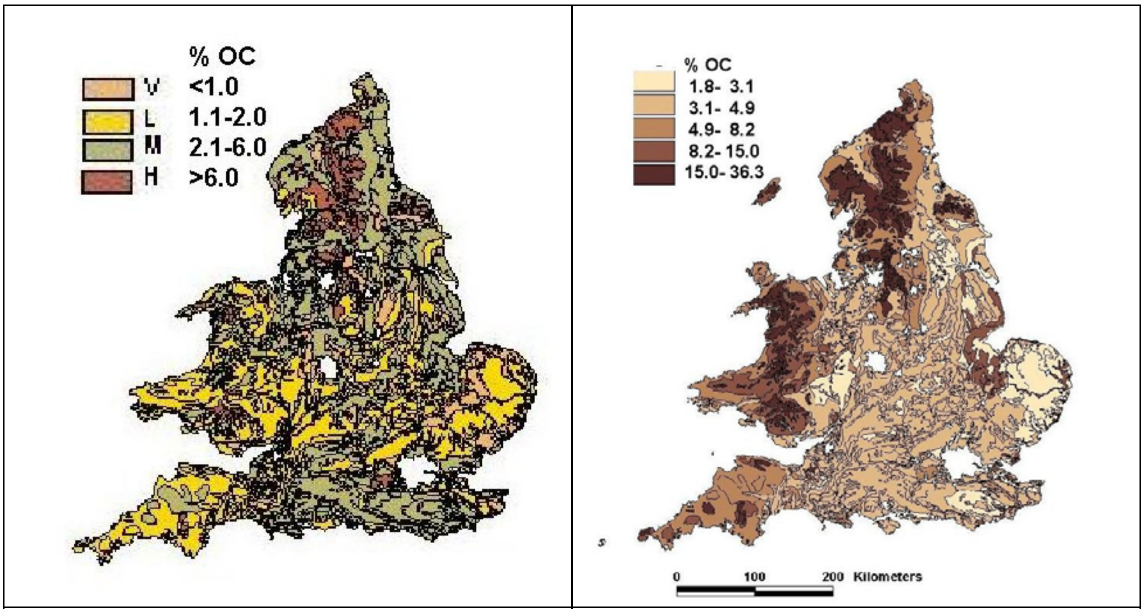
For other kinds of elaboration, the European Soil Database has also proved to be useful. For example, the database has been used to calculate the organic carbon stock for Italy. This analysis was made using the median value of each of the classes of OC content. For the class OC>6% a median value of 10% was chosen for linking with the Soil Mapping Unit. The result of this analysis was compared with results from external studies, for example the "Assessment of Carbon sinks in vegetation and soil for the European Union" (CNIG, 2000).

**Table 4 Estimated soil organic carbon stocks in Italy**

| **OC study** | **Carbon stock (Pg [$10^{15}$ g])** |
|---|---|
| Derived from European Soil Database | 2.289 |
| Derived from ISRIC-WISE Database | 2.278 |
| **Difference** | **0.011 (0.5%)** |

In the CNIG study, the soil carbon stock was derived using the World Inventory of Soil Emission Potential database prepared by the International Soil Reference and Information Centre (ISRIC-WISE). The results are compared in Table 4. The OC stock in the soils of Italy derived from ISRIC-WISE was calculated to be 2.289 Pg ($10^{15}$g) or gigatonnes and from European Soil Database was 2.278 Pg ($10^{15}$g), gigatonnes. This is a difference of 0.011 Pg ($10^{15}$g), or only 11 million tonnes corresponding to 0.5%. It should be emphasised that both these databases were compiled at the continental level and contain data collected several decades ago.

### 2.3.2 Organic carbon levels in UK soils



**(a) Organic Carbon content from European pedotransfer rule**

**(b) Mean Organic Carbon content from UK National Soil Inventory** [after Loveland, Silsoe]

***Figure 5 Organic Carbon contents in the topsoils of UK on the basis of European Soil Mapping Units (SMU)***

In the UK, a National Soil Inventory (McGrath and Loveland, 1992) was undertaken on a 5km x 5km grid with sampling made for the first time in 1981-83 and then a re-sampling in 1995-97.

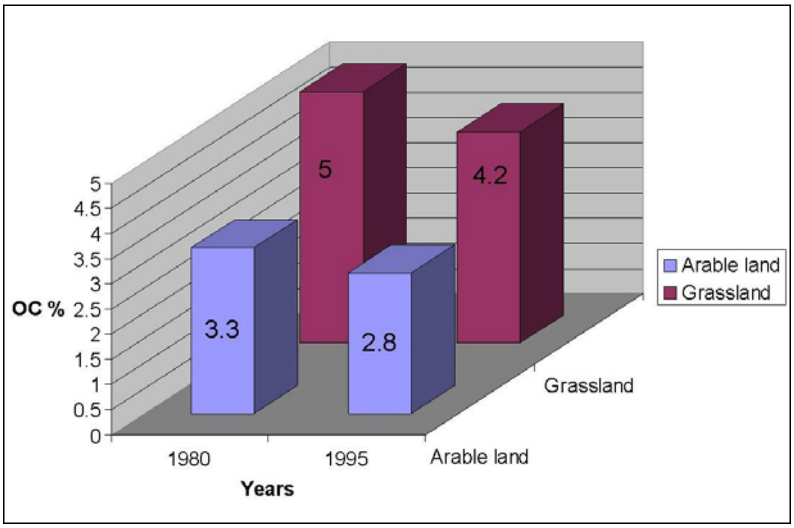
Figure 5 shows the data obtained for UK at National level linked to the SMU from the European Soil Database (Loveland, pers. comm.). The differences between the organic carbon values obtained from the European Soil Database (pedotransfer rule) and those measured during the National Soil Inventory, and summarised on a European SMU basis are significant. Such comparisons are complicated by the fact that OC class limits are different but the disparity is clear.

### 2.3.3 Organic carbon stocks in France

Arrouways *et al.* (2001) have studied the carbon content of topsoil in France and its geographical extent. The organic carbon content was estimated to a depth of 30cm using georeferenced databases. Analysis showed that the main controlling factors of the carbon distribution are land use, soil type in some cases, clay content and elevation. Total carbon stocks in France were found to be about 3.1 Pg ($10^{15}$g) which is in the same order of magnitude as the 2.3 Pg ($10^{15}$g) calculated for Italy.

## 3 Evolution and tendencies in Organic Matter content

The European Soil Database (King *et al.* 1995, Le Bas *et al.* 1998) and the ISRIC-WISE database (Batjes, 1996, 1997) can provide an insight to the existing geographical distribution of organic matter in European soils, albeit a very approximate picture. However, such databases cannot shed any light on past changes or future trends in organic matter content. The long term experiments in the UK and USA, described by Zdruli *et al.* (1999), give an indication of the likely decline that has taken place in intensively farmed arable areas over the past century. In Mediterranean areas where some soils have been cultivated for more than 2000 years, the decline in natural levels of organic matter may be much larger.



*[after Loveland, NSRI, Cranfield University, Silsoe]*

***Figure 6 Change in organic carbon content of topsoils in England and Wales***

In practice, the only way to establish trends in the organic matter content in future is to monitor organic carbon/matter levels periodically. This means setting up a comprehensive soil-monitoring network. There have been a few attempts in European countries to monitor changes in the basic soil parameters over time during the past 40 years but these are so sporadic that they are no substitute.

Some results, for example from France and United Kingdom, give an insight into what is needed at European level. The data at National level have been analysed according to land use and the results (Figure 6) linked with the soil map units of European Soil Database that cover England and Wales. These data show a decline in the organic carbon content in England and Wales under different land use between the two sampling periods, 1981-83 and 1995-97. It is important to focus attention on the fact that in UK the climate should be favorable to the accumulation of OC in the soil. These first results for UK lead to the conclusion that the major causes of the decline in OC are cultivation, resulting in oxidation of organic matter, and land use change, e.g. the conversion of permanent grassland to arable use.

## 4 Conclusions and Recommendations

The results from the studies described above probably represent the best information that can be obtained from the digital soil databases for Europe that currently exist. Addressing the issue of soil quality in general, and that of organic matter content in particular, is now of such high priority for planning the sustainable use of land resources that much better data need to be assembled for the whole of Europe. These data must be georeferenced and have a strong temporal component. The scale and precision need to be significantly better than the Soil Database of Europe at 1:1,000,000 scale. Furthermore, in incorporating more national data, the harmonization of methodologies particularly between the various soil survey organizations must be given a high priority.

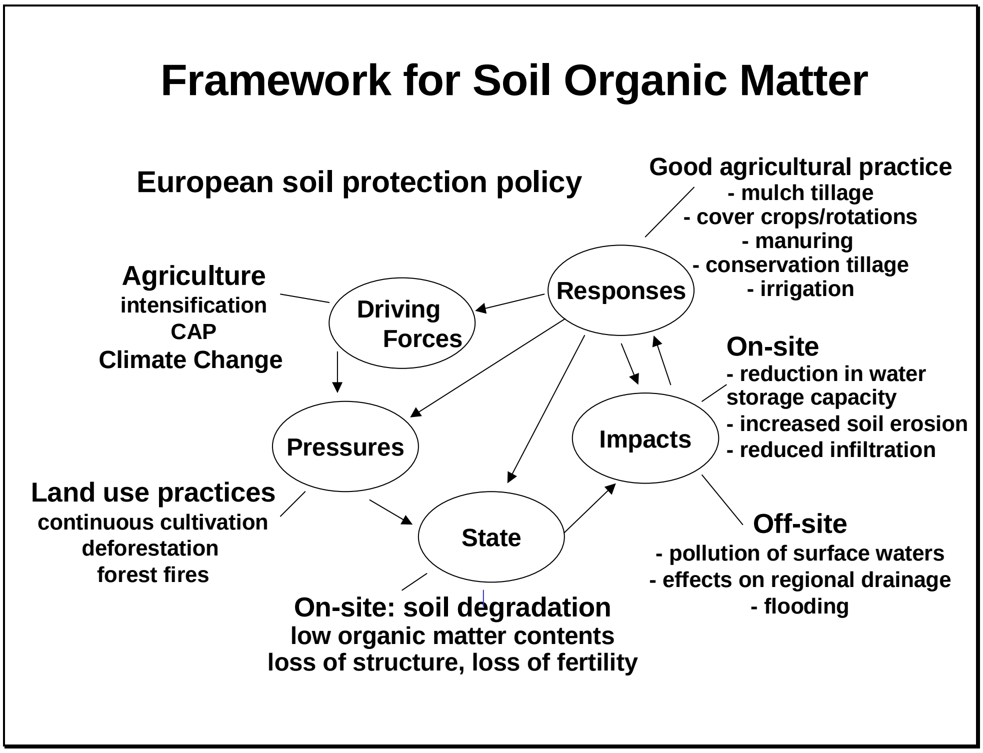


*Figure 7 The DPSIR Framework applied to soil organic matter*

The European Soil Bureau, in consultation with the ESB Network (Montanarella and Jones, 1999), has prepared a manual of procedures for constructing a Georeferenced Soil Database of Europe at 1:250,000 scale (ESB, 1998). This manual has been translated into Italian (ESB, 1999a), Spanish (ESB, 1999b) and French (In prep). These developments together with the development of the European Soil Information System, represent a significant step forward. However, to provide the policy making process with a sufficiently firm foundation for much needed soil protection measures, a comprehensive soil monitoring network across Europe is urgently needed.

In summary:

1. The only homogeneous data at European level on organic carbon (OC) content in the soil must derived from a pedotransfer rule applied to the European Soil Database at scale 1:1,000.000.
2. The results from the European Soil Database can only give an approximate picture of the soils of Europe and any information, with respect to organic carbon, derived from it must be regarded as preliminary only.
3. Comparison of the results at National level and European level show some large differences.
4. Available data were mostly collected many years ago and now need updating.
5. Much more data about OC content in the soils of Europe are needed to run models that can predict the evolution of OC.
6. Many more samples must be taken in space and time to evaluate the changes and trends in the OC content in soil, especially in relation to land management.
7. A common framework is needed to define the methodology for collecting and analysing the data and to organize a comprehensive Soil Monitoring Network at European, National and Regional levels.

Finally a schema similar to that shown in Figure 7 needs to be adopted to facilitate transfer of the results of scientific research into information that can be used for policy making. This framework – DPSIR (OECD, 1993), encompasses the driving forces and pressures affecting soil organic matter. It also identifies the impacts and helps to link in the much-needed responses that could prevent further decline.

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