CURRENT STATUS OF RISK ASSESSMENT METHODOLOGIES FOR SOIL ORGANIC MATTER DECLINE

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GLOSSARY

Elements at risk:
Fields, elements of landscapes, landscapes, soil and their pedons in an area potentially affected by a decline in organic matter.

Organic matter decline:
A soil biological, biochemical and physical phenomenon that results in a decline of the content and stock of organic matter by interaction of biotic and abiotic soil processes.

Or

The threat ‘decline in soil organic matter’ is defined as: a negative imbalance between the build-up of soil organic matter and rates of decomposition leading to an overall decline in soil organic matter contents and/or quality, causing a deterioration or loss of one or more soil functions.

Hazard:
Property of a threat having the potential to cause unfavourable effects.

Risk:
The probability of an unfavourable effect in a system by exposure to a threat.

Risk assessment:
A process to calculate or estimate the risk to a system, following exposure to a particular threat.

Vulnerability:
Liability to injury or damage.

Abbreviations:

EEA	European Environmental Agency
EU	European Union
GIS	Geographical Information System
GLASOD	Global Assessment of Soil Degradation
RAM	Risk Assessment Methodology
SOM	Soil Organic Matter
SOC	Soil Organic Carbon

Abstract

The objective of the RAMSOIL project is to provide scientific guidelines for EU wide harmonization concerning Risk Assessment Methodologies for soil threats. This report focuses on the soil threat '*decline of soil organic* matter' and specially focusses on assessment of contents.

A survey on RAM's on soil organic matter decline among scientist of EU countries was complemented by an exploration of scientific literature. For the survey questionnaires were send to 26 specialists of which 16 of them from 11 countries returned a response. The overall response was general with few possibilities for specification of details on RAM's.

There are currently no official RAM's on organic matter decline in use in any of the 27 EU countries. The decline of soil organic matter (SOM) or soil organic carbon (SOC) is however subject to research of national institutions in several countries. Monitoring systems of SOM/SOC decline for an official RAM are currently being developed in 5 countries. Reviewed literature showed that information on possible organic matter decline can be obtained from monitoring systems on soil quality.

Assessment methods are based on empirical methods or statistical models or mechanistic models. Empirical observational methods are simple and widely accessible. The scale, which leads to high data demand, can increase the cost. These methods are highly transparent. However differences in determination of SOM or SOC during coarse of time, the lack of referenced and measured bulkdensities and the lack of methods for derivation threshold values for critical values for SOM (or SOC) leads to ambiguousness.

Except for decline of SOM caused by erosion (landslides, water and wind), changes in hydrology (groundwater table), deforestation and conversion of grassland to arable land the decline in SOM in time is a slow process. This makes any decline difficult to assess. Trends that use historical data may be hampered by additional bias caused by changes in methods for SOM (or SOC) determination and lack of information on bulk densities. Moreover, methods that use data from long-term field experiments or surveys on soil fertility of farms are biased by differences caused by changes in land use during the period of observation and this causes any changes difficult to attribute to a specific cause. Changes in SOM or SOC require time and are therefore costly. A decline in SOM is therefore not unequivocal to assess. Reported declines (or increases) raised discussion on the methods for derivation. There is a debate whether a reliable threshold for SOM (or SOC) can be derived as SOM or SOC contents of a soil type reflects landuse, management and climate. Although a characteristic SOM content for a specific soil type generally can be given, no RAM's are available on the assessment of a decline that causes a risk as referenced values are lacking. It is conceivable that thresholds for specific systems of

land use and soil type - combined with water tables - will find general acceptance. The lack of thresholds hinders development of RAM's and the design and efficiency of monitoring networks. Mechanistic methods (models) are more complex en thus less transparent. Their scale and data demand differ but are in general more cost-effective than empirical methods with large data demand. Most models work up to equilibrium in steady state at a constant supply of organic matter and constant conditions (climate, management) but there are differences in the time which is required to reach this equilibrium. Because these models use a dynamic equilibrium they provide options for harmonization. Options, if standadisation is needed, are given by rather complex models as CENTURY, Roth-C or CANDY . Though these are complex models, they have gained wide acceptance through their flexibiltity to model soil processes for a variety of soil types, management and climate, through it's soundness and predictions. The high flexibility provides a sound basis for analyzing current conditions and future scenario's for a dynamic land use.

Policy summary

This evaluation of Risk Assessment Methodologies for the threat of a decline of soil organic matter has shown that no EU country currently possesses an officially recognized RAM. This treat is currently not recognized as an official problem. However 5 countries are currently working on the implementation of a RAM on organic matter decline according to the results of the questionnare. Table 1 shows the status of the countries working on the development of a RAM on organic matter decline.

Table 1. Status of the Risk Assessment Methodologies (RAM's) on soil organic matter decline in the European Union.

Status Risk Assessment Methodologies	Countries
Official assessment in development	Belgium (Flanders), France, Slovak republic[1], Spain, United Kingdom
Assessment used by an institution	Belgium (Wallonia), Slovak republic, Slovenia, Slovak Republic.

[1] Slovak republic reported an official RAM in development as well as RAM used by an institution.

The RAM's that are currently being developed differ in design and scale. There is no common method for deriving thresholds values. Moreover, there is debate whether a threshold should be derived or not. Threshold values currently given by some EU countries do differ as a result of the data collection, their method of derivation, their application/scope and function. Harmonisation on the method of derivation, reference values and use of threshold values are required.

Contents

Preface

This report on the soil threat for a decline in soil organic matter is part of the RAMSOIL project (European Commission contract no. 44240). Current Risk Assessment Methodologies (RAM's) on soil organic matter decline are presented, reviewed and evaluated. Similarities and differences between concepts of RAM's are given and discussed. Observations on organic matter decline are some EU countries are presented. Current state on monitoring soil organic matter decline is given.

This report elaborates on the aspects dealt within the EU report concerning the Thematic Strategy for Soil Protection (CEC, 2002), and also in the reports from Eckelmann et al. (2006) and Heesmans (20070, all three of them providing scientific support to policies. Whereas the former reports comprise information and provide evaluation of soil degradation processes in general, the current report focuses on risk assessment of soil organic matter decline as a specific threat.

1. Introduction

Soils contain vast amounts of organic carbon (C). On a global scale, about 1500 Pg (1 Pg = 10^{15} g) is stored in the upper meter of the soil, which is about three times the amount of C in the aboveground biomass and twice the amount of C as CO_2 in the atmosphere (Batjes, 1996; Janzen, 2004). Most of soil C is found in the upper 10 to 20 cm of the soil, and the amount and quality of C in the topsoil is often used as indicator of soil quality and productivity (Allison, 1973; Bauer and Black, 1994; Davidson, 2000). In agriculture, increasing soil organic C (SOC) content is often seen as a desirable objective, especially in organic farming (Mader et al., 2002; Lovelock and Webb, 2003; Lal et al., 2004), though the benefits of organic C in soil in terms of fertility arise in part from its decay and not from its accumulation (Janzen; 2004; 2006). Sequestration of C in soils has also been promoted as strategy to mitigate the effects of increasing emissions of greenhouse gases in the atmosphere (Lal et al., 1998; 2001; Janzen, 2004).

Some recent studies suggest that SOC of European agricultural land is decreasing (Vleeshouwers and Verhagen, 2002; Sleutel et al., 2003; Bellamy et al., 2005). Such decreases are ascribed to changes in land use, soil cultivation and, possibly, climate change (Davidson and Janssens, 2006). Jones et al. (2005) calculated that 0.6% of soil carbon in European terrestrial ecosystems is lost annually. Farmers have concern that decreases in SOC compromises the production capacity of the soil by deterioration of soil physical properties and by impairment of nutrient cycling mechanisms (e.g., Loveland and Webb, 2003). Another concern is the loss of organic matter of organic soils (peat soils, plaggensoils) which causes soil subsidence and an increase of greenhouse gases (Smit e.a., 2007). Soil subsidence can lead to a (relative) increase of the groundwater table. Otherwise anaerobic soil layers may become aerobic which may promote soil processes which deteriorates soil further (for instance winderosion, soil compaction or even oxidation of cat clays). In lowlands this can lead to an increase of the risk on flood (overflow) and an increased cost for maintaining the infrastructure and buildings (Smit et al., 2007).

Some arable farmers in the Netherlands are using these arguments to criticize governmental restrictions on the use of animal manure and composts, although these restrictions are meant to regulate the inputs of nutrients and heavy metals. Additions of animal manure and composts are often perceived as inherently desirable.

In EU-25, most soils are out of equilibrium as regards soil organic matter contents, as they have been affected by land management practices and land use (Smith et al., 2005). JRC-IES has compiled a soil organic matter map for Europe (Figure 1). Whether the information in the European soil map is up to date remains uncertain as very few national monitoring programs of soil organic matter exist and the 65 existing monitoring networks in the EU on soil quality are not set up to provide information for the soil map. Assessments of changes in soil organic matter suggest that in cropland soil carbon stocks in general continue to decline perhaps as a result of recent land use change or agricultural management, e.g. tillage practices or manure use (Smith et al., 2005; Vleeshouwers and Verhagen, 2002; Freibauer et al., 2004). The values for cropland soil carbon loss however are highly uncertain (Janssens et al., 2003).

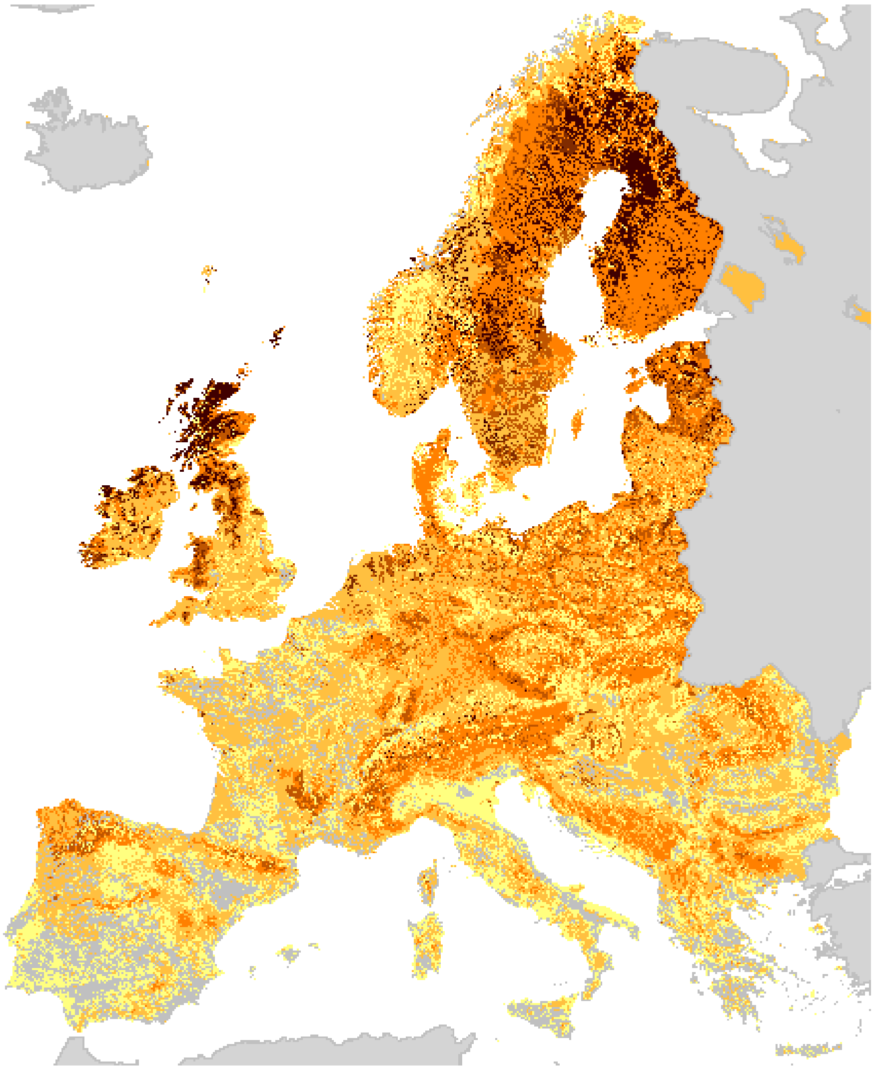

Figure 1. Soil organic matter in Europe (Jones et. al, 2005).

However, despite the common felt loss of organic matter there are few consistent methodologies to identify areas at risk. In this paper an overview is given on currently used methods and gaps in implementation and developments of methodologies.

2. Risk assessment methodologies

Risk assessment methodologies generally consist of four consecutive steps:

1. data gathering; via direct measurements
2. data processing; via simulation models, pedo-transfer functions, regression statistics etc the data is processed into the targeted risk indicator.
3. data interpretation; the risk indicator is compared to a certain threshold value.
4. risk perception; the deviation of the risk indicator from the threshold value is assessed.

In this paper each step is evaluated and different methods are compared using questionnaires that were sent to national respondents and deepened with a review of literature.

3. Response to questionnaires

In total 26 soil organic matter questionnaires were distributed within Europe. The questionnaire focused on the scientific as well as on the policy related aspects of RAM's for soil organic matter (RAMSOIL report MR 1). The questionnaires were sent to national representatives that are responsible for the development and/or implementation of soil organic matter Ram's.

In total 11 countries returned 16 questionnaires. The countries were Belgium (Flanders, Wallonia), Denmark, France, Finland, Germany, Greece, Poland, Spain, Slovenia, Slovak Republic and United Kingdom.

None of these countries uses an official RAM on soil organic matter decline. Next, five countries reported that a RAM is currently being developed for monitoring purposes, i.e. Belgium (Flanders), France, Slovenia, Spain and United Kingdom. RAM's are used by institutions in Belgium (Wallonia), Poland, Slovenia and Slovak Republic.

Across Europe few countries have designed and implemented monitoring networks for soil organic matter. The survey showed that institutions of 6 countries used a RAM based on some form of monitoring system and 5 countries are developing a monitoring system.

The overall absence of monitoring and data makes it very difficult to engage with soil management in the Kyoto Protocol obligations on a European level. JRC ISPRA has recently suggested a monitoring strategy for organic matter in soils across Europe (Stolbovoy et al., 2005, 2006, 2007a, 2007b).

In conclusion the comparison to questionnaires on other soil threats, the response was in general low. This is attributed to the lack of effective RAM's and an unawareness of the soil threat on SOM decline. But also, the poor redistribution of the questionnaires amongst addressees hampered insight in RAM's of Europe. Also from other discussions and documents (e.g. Smit et al., 2007) it is clear that that the systematic and structural national assessment of SOM decline in practice has yet to be initiated. Currently used methods are only applied at local regional scale. Notably, during a workshop in The Netherlands with policy makers and stakeholders the risk of SOM decline was little anticipated. The sense of urgency by Member States for developing a RAM on SOM decline from the perspective of a soil threat appears to be small. As long as the *actual* risk perception of a possible SOM decline is still weak, policy makers seem rather reluctant on initiating RAM's for soil organic matter decline. The issue of the importance of increasing the soil organic matter stock to combat the increase of CO_2 in the atmosphere is marked out in this RAMSOIL report on RAM's.

4. Literature review

In a number of recent papers datasets of soil sampling were evaluated, and trends in SOC contents on a regional or national scale were found. In the following paragraphs some results from Flanders, England and Wales, and The Netherlands are summarized.

4.1 Belgium Flanders

Changes in soil carbon stocks of Flemish cropland soils were calculated by Sleutel et al. (2003) for the period 1989-2000. Their estimation was based on 190 000 soil organic carbon (SOC) data that were collected for the 0-24 cm soil layer of farmer's fields. Data were grouped based on soil texture and spatial location. Figure 15 shows for the 27 groups the calculated change in the SOC content. Weight-averaged the mean decrease in SOC was -0.174 % year^{-1}. This contrasts with findings by Heidmann et al. (2002, cited in Smith et al., 2007), who reported no decrease in SOC for Danish croplands, and Dersch and Boehm (1997, cited in Smith et al., 2007), who reported the same for Austrian soils. The relatively large decrease is ascribed to the restriction by law of the use of animal manure on cropland, starting in 1990 (Sleutel et al., 2003, Lettens et al., 2005). Also, erosion caused by intensified management on erodible arable land is mentioned as a possible cause of loss in SOC (Lettens et al., 2005).

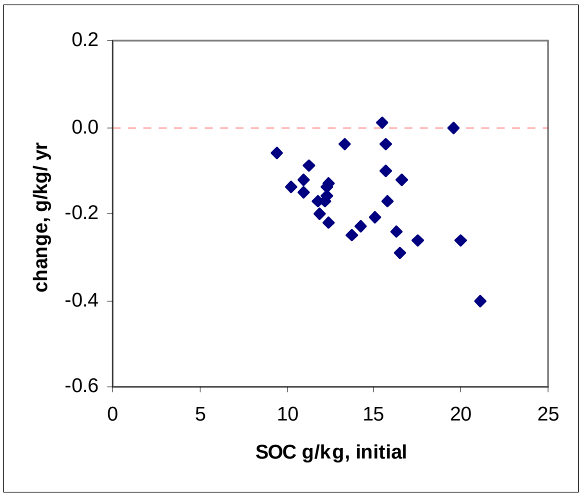

Figure 2. Change in SOC in Flemish arable soils in the period 1989-2000. Data from Sleutel et al. (2003).

In a more detailed analysis of the data, it was found that the change in % SOC was positively correlated with the number of livestock per ha cropland in different communities in the region Leuven (Sleutel et al., 2003, Figure 3).

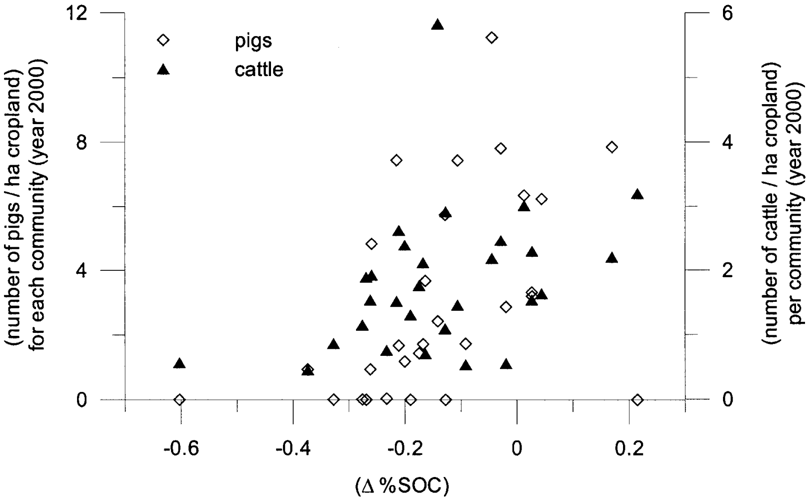

Figure 3. Scatter plot between the livestock density per community (number of livestock units per hectare cropland) in the Leuven district and the difference between the mean SOC content per community with the Flemish average SOC content of the corresponding textural class (Δ% SOC) (from: Sleutel et al., 2003).

This implicates that a high animal density in a community had a positive influence on the change in local SOC, which can probably be explained by a larger amount of manure used per hectare.

4.2 England and Wales

For England and Wales, Bellamy et al. (2005) summarized SOC data from the 0-15 cm soil layer, determined between 1978 and 2003. The data were grouped on the basis of their original SOC content. Figure 3 shows the relation between the initial SOC content and the change in SOC during the period of study, for different ranges of SOC (0-20-30-50-100-200-300- g/kg). The left figure shows the absolute changes (g/kg/yr), the right figure the change as % of the mean original SOC. Note that the range in values of initial SOC is 20 times the range of the data shown in Fig. 1 for Flemish arable soils. The absolute value of the change in SOC is strongly linear correlated with the initial SOC content; the equation for the line is:

$$\text{Rate of change in SOC} = 0.6 - 0.0187 \text{ x } SOC_{in}$$

The relative values (% of SOC_{in} per year) decrease very strongly with SOC_{in} in a non-linear way (Figure 4, right).

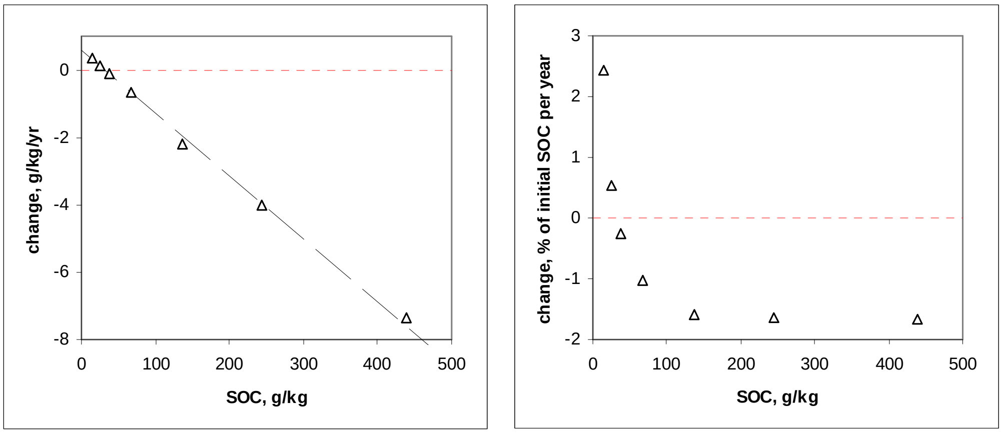

Figure 4. Change in SOC in soils from England and Wales in the period 1978-2003. Data from Bellamy et al. (2005). Left: absolute values, right: relative values.

In a paper by Smith et al. (2007), the results of Bellamy et al. (2005) were discussed. Several possible explanations were given for the decrease found by Bellamy et al.:

- A decrease in the number of animals, leading to less manure being applied
- More efficient removal of crop residues
- Increase in production of silage in place of hay, leading to removal of more residues and decrease in SOC
- Deeper ploughing depths, leading to more mineralization and diluting surface SOC levels
- Legacy effects of land use change occurring before 1978, effects of this are visible after more than 120 years.

According to Smith et al. (2007) these factors mentioned above cannot be excluded in the study of Bellamy et al. (2005), so can possibly explain (part of) their results. However, these factors can not explain the large decrease in mg/kg/yr (Fig. 2 left) of SOC in organic (peat) soils (Smith et al., 2007).

4.3 The Netherlands

In a paper by Reijneveld et al. (2008), data from a data base with 2 million results of soil analysis on SOC from farmers' fields were discussed. All samples were taken and analyzed by one laboratory (BLGG in Oosterbeek) during the period 1984-2004. Three land use types were distinguished: arable land, grassland and maize land. All data were grouped in nine specific regions and were analyzed for trends in SOC over time and for differences between regions. Figure 5 shows the trends for the 13 combinations of region and land use type, with a linear line fitted through the data for comparison with the line calculated by Bellamy et al. (2005) for their data.

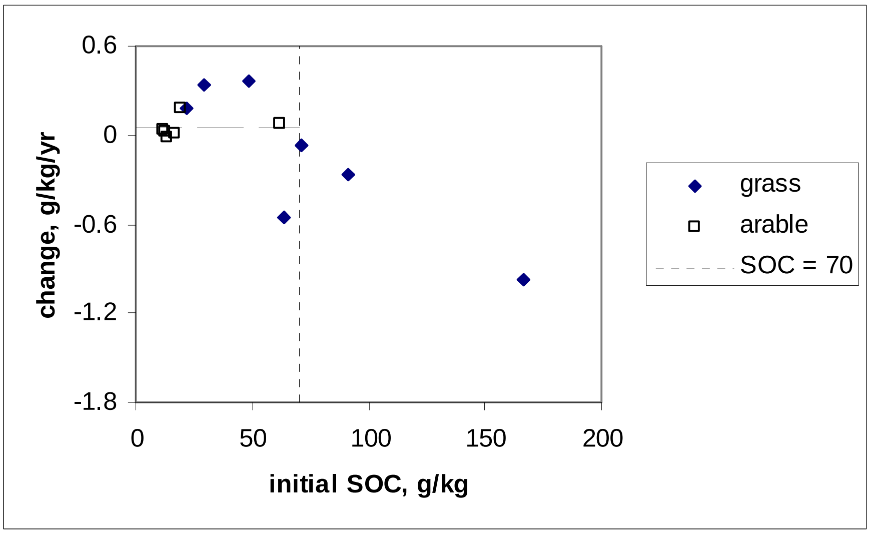

Figure 5. Change in SOC in grassland and arable soils in 13 different combinations of region, soil type and crop from The Netherlands in the period 1984-2000. Data from Reijneveld et al. (2008). The horizontal line shows the weighted average trend for categories with SOC_{in} *< 70 g/kg.*

In Figure 6 the data (and trends) presented in the papers for Flanders, England and Wales and The Netherlands are combined. From this figure and Figure 5 it is clear that the arable soils from Flanders, and 5 out of 6 regions in The Netherlands, the SOC content is very low when compared to most of the grassland soils in the Netherlands, and to most of the samples reported from England and Wales.

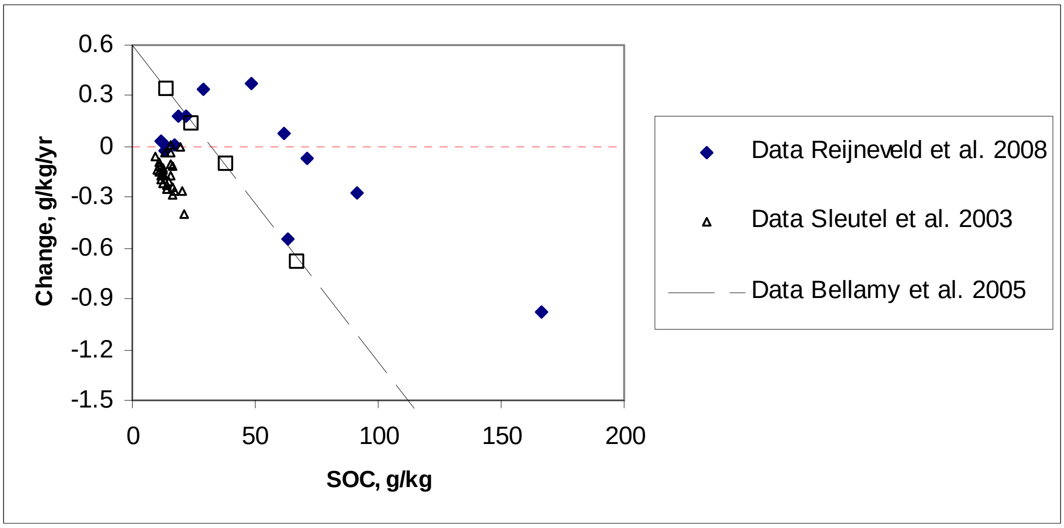

Figure 6. Change in SOC in soils from The Netherlands (1984-2004, Reijneveld et al., 2008), England and Wales (1978-2003, Bellamy et al., 2005), and Flanders (1989-2000, Sleutel et al. (2003).

What remains remarkable is that for most of the regions in The Netherlands an increase in SOC was found by Reijneveld et al. (2008, Figure 5). This might be explained by the large amount of manure applied in The Netherlands. The amount that is allowed to be used has also reduced in the Netherlands (Chardon and Koopmans, 2004). However, it still amounts to ca. 45 ton animal slurry/ha/yr under the new EU regulation for arable land, and 55 ton/ha/yr on grassland (limits resp. 180 and 250 kg N/ha/yr from manure, with the N-content of manure estimated as 4.5 g N/kg). In addition, the scale on which a decline in SOM is determined effects the conclusion. Hanegraaf et al. (2008) analysed trends in soil organic matter in Dutch grassland and maize fields on sandy soil. These subsets comprise of series of soil sampling in the period 1984-2004. Four to five series were available totalling an average 15,500 fields/per year. The series are part of routine agricultural soil analyses for fertiliser recommendations. Time-serie analysis of SOM at field level showed no significant changes in SOM in the period 1984-2004 on grassland, continuous maize land and grass-maize rotation. This confirmed the observations of Reijneveld et al. (2008). However the fields with continuous maize with initial the highest SOM did show a tendency for a decline in SOM. Hanegraaf et al. (2008) concluded that fields with continuous maize on sandy soils SOM is expected to continue to decrease and could reach a lower limit of 2%C in the near future. For grassland no uniform trend at present nor in the near future can be given. This Dutch experience shows that the threat of soil organic matter decline in intensive agriculture requires identification of high risk fields with specific land use rather than high-risk areas.

Smith et al. (1997) reviewed 14 studies in which variable amounts of manure were added to soils in long-term field experiments. The SOC content in the 0-30 cm soil layer was determined for treatments with or without manure addition. From their data, the increase in SOC was calculated per ton manure applied per year. The results are presented in Figure 7.

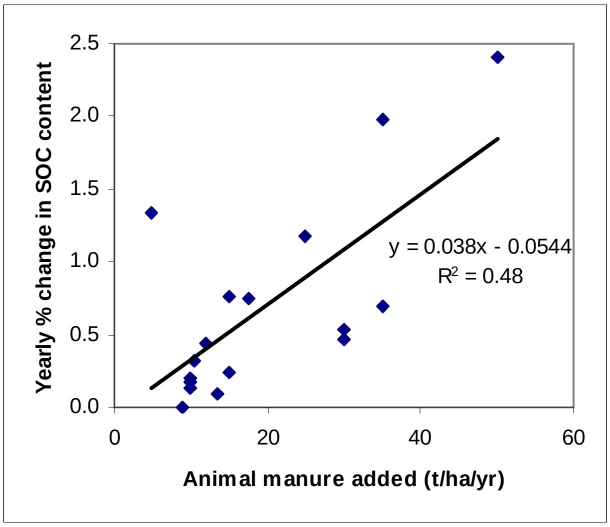

Figure 7. Influence of the amount of animal manure added on the yearly change in SOC in 14 soils from long-term field experiments, reviewed by Smith et al. (1997, their table 3).

The regression equation shown in Figure 7 was used to estimate the predicted increase in SOC (% of SOC_{in}) for different amounts of manure used. In Figure 21, these predictions were compared with the data found by Reijneveld et al. for the yearly increase in SOC, also expressed as % of SOC_{in}. From this figure it can be seen that the relative increase in SOC in 8 out of 13 regions in The Netherlands can probably be explained by addition of 20-40 ton manure/ha/yr. These are amounts that were very common in the past, especially on sandy soils in Southern and Eastern parts of The Netherlands.

At present, the possible explanation of the increase in SOC in different regions is tested using the CENTURY-model.

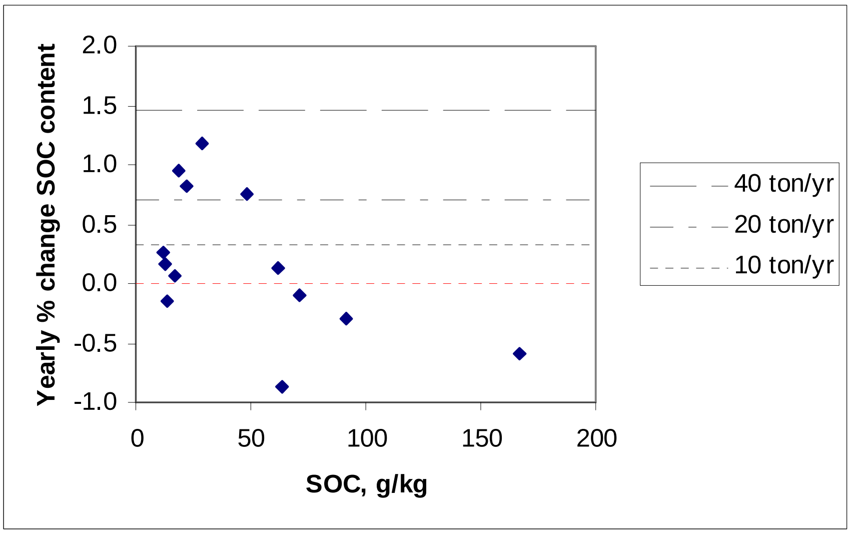

Figure 8. Relative change in SOC in grassland and arable soils in 13 different regions from The Netherlands in the period 1984-2004 (data from Reijneveld et al., 2008). Drawn lines correspond with the equation derived from the data from Smith et al. (1997), see Figure 7.

Though SOM/SOC contents are of considerable interest and in principle can be measured easily, there are few monitoring programs that allow systematic analyzing possible changes in SOM/SOC in agricultural land in practice (Janssens et al., 2005; Stolbovoy et al., 2005, Spiegel et al., 2007). Current estimates of changes in SOC at national and continental levels are therefore uncertain (Janssens et al., 2003). So far, most estimates are either derived from long-term field experiments (e.g., Jenkinson and Rayner, 1977; Wadman and de Haan, 1997) and/or simulation modelling (Jenkinson et al., 1987; Jenkinson, 1988; Yang and Janssens, 2000; Vleeshouwers and Verhagen, 2002; Freibauer et al., 2004; Vellinga et al, 2004; Smith et al., 2005). Few studies have used repeated inventories for estimating changes in SOC at regional scales (Sleutel et al., 2003; Lettens et al., 2004; Bellamy et al., 2005).

5. Data gathering

RAM's on soil organic matter decline are based on schemes for sampling soil of fields or (high risk) areas, frequency of sampling, analysis of soil and methods for data handling/data processing. However as there are no official RAM's on soil organic matter decline, the data gathering serves other purposes amongst others establishing soil maps, characterizing carbon stocks, serving fertiliser recommendations, characterizing soil quality (contaminants) and such on. The objectives for the data gathering differ from the objective to deterimine a decline in SOM/SOC and this affects sampling schemes, frequency of sampling, sampling depth and data handling/data processing.

5.1 Sampling schemes

Sampling schemes differ between countries and even within a country. Several forms of sampling schemes can be distinguished; amongst others:

1. None systematic schemes for characterizing a soil type;
2. Systematic schemes;
3. Data collected from soil sample analysis for establishing fertilizer recommendations based on soil testing.
4. Soil chronosequences.

None systematic schemes are used to identify characteristic soils for a given area (classic chronosequences). The sampling does not follow a systematic grid. From a representative location the soil is characterised and classified. Sampling of the soil profile is part of it's classification. Soil profiles (georeferenced) are elements of the national soil surveys. The density of the locations depends of the patterns in soil types. As these soil profiles have been meticulously described and their characteristics measured (one of them being SOM or SOC) revisiting these sites provides in combination with appropriate geostatistical methods a relatively efficient method to establish a trend in SOM or SOC. Still, large numbers of new observations may be required. However, not all soil profiles are georeferenced. The questionnaires of Belgium (Wallonia) and Poland mentioned the use of georeferenced soil profiles. The questionnaires pointed out that in 2007 georeferenced soil profiles are still not common throughout EU. This reconfirms the findings of Jones et al. (2004, 2005).

Grid methods are used or are currently developed in Austria, France, Denmark, United Kingdom (England, Wales, and Scotland), Northern Ireland, Ireland, Germany, Hungary and Poland). These are national grids which were established for national soil surveys. Grids can be complete systematic or heterogeneous and based on a spatially irregular selection of sampling locations using expert judgement (Morvan et al., 2008). The differences in scale lead to differences in resolution. The questionnaires do not give information on the patterns of the grid (random, nested, systematic, stratified and such on). Most likely the pattern will differ amongst countries.

The scale of sampling schemes for (georeferenced) soil profiles and grid methods differ in scale. Scales from 1:5,000 to 1:1,000,000 are used (table 2). A soil map of the EU on the scale 1:1,000,000 and characteristic SOM contents is available (Jones et al., 2004, 2005). Resampling of (georeferenced) soil profiles is preceded by a selection of sites that meets current requirements on representative of soil types and factors that effects a decline of SOM or SOC (example given landuse). Sampling size is notably determined by minimum detection levels of SOM or SOC change which is conditioned by the initial SOM or SOC content in combination with the analytical method for determination. Preliminary studies are conducted to enhance the efficiency of the resampling, to increase the robustness of the trend in SOM or SOC and to reduce costs.
Within the ENVASSO 65 monitoringsnetworks have been identified with in total 36104 locations where soil quality is measured. Of these 33334 locations provide infromation on SOM.

Table 2. Scales reported in questionnaires on sampling schemes of soil.

Country	Scale
Belgium (Flanders)	1:1,000,000
Belgium (Wallonia)	1:20,000, 1:25,0000
France	1:250,000 to 1:1,000,000
Greece	1:5,000
Poland	1:10,000
Slovak republic	1:400,000
Slovenia	1:10,000, 1:20,000, 1:25,000
Spain	1:50,000
United Kingdom	1:250,000

Soil sample analysis for establishing fertiliser recommendations provides large databases on soil characteristics. These samples are not based on formalised national or regional sampling schemes but are in general send in by cooperation's, advisers or farmers for guidance on the use of fertilisers. In general, these soil samples will represent agricultural land that has suboptimal soil fertility and therefore might not represent an objective reference for a decline in SOM for a nation or region. Nevertheless, these surveys do give information on these soils with suboptimal soil fertility and can show trends on a decline in SOM of this specific group of soils (which does not necessarily include SOM).

The sampling scheme for collecting representative soils samples for establishing fertiliser recommendations can follow a grid method but often a W- or Z-shaped pattern or a geostatistical pattern is followed. The number of soil cores differs with the plot size and is in general more determined by nutrients than by the determination of SOM or SOC.

Soil sample analysis for establishing fertiliser recommendations provides large databases on soil characteristics. These samples are not based on a formalised national or regional sampling scheme but are in general send in by farmers who need guidance on their use of fertilisers. The soil samples will mainly represents agricultural land that has suboptimal soil fertility and therefore might not represent an objective reference for a decline in SOM for a nation or region. However, these surveys do give information on soils with suboptimal soil fertility and can show trends on a decline in SOM of this specific group of soils (which does not necessarily include SOM). The data of these databases are often not accessible as the farmer is the proprietor of the data. Anonymised and scaled to larger areas data can be made available.

Soil chronosequences are genetically related suites of soils evolved under similar conditions of vegetation, topography, and climate (Harden, 1982). They translate spatial differences between soils into temporal differences (Huggett, 1998). Soil chronosequences (space for time substitutions with confounding of space and time) are instruments of pedological investigations. They have been used to determine carbon sequestration is soil and biomass following afforestation (Vesterdal et al., 2007). As such it is a different technique in determining changes in a soil parameter such as SOM/SOC. Although a revisiting of sites can take place, often comparison of sites with comparable characteristics but differences in management (tree species, fertilisation, forest age) pinpoints chronosequences.

Soil sampling and sub sampling

The questionnaires did not provide information on the soil sampling methods used in the EU countries. However the number of soil cores, the auger, the sub sampling of the soil sample from the field, soil sampling depth, frequency of sampling, pre-treatment of soil samples is known to differ between EU countries and within EU countries. Moreover, as these methods have been changed during the course of time, an additional bias is introduced which influences comparison of declines in soil organic matter between countries and within a country. Also the soil sample from the field is too large for transport of handling on the laboratory. It is therefore subsampled to reduce size. Also the methods for subsampling differ. In this deliverable these aspects are not further discussed. Sample pre-treatment nowadays is standardized (ISO 11464: 2006 and ISO 23909:2008 for large samples) but current methods will differ from sample pre-treatment in the past.

5.2 Frequency of soil sampling

The period of assessment differs between countries that have an unofficial RAM. United Kingdom and Slovak Republic can assess a decline in SOM over a period of at least 15 years. The RAM of Belgium (Wallonia) is effective since four years while Spain and Poland just recently started the use of their RAM's. Other countries (Denmark, Germany, Netherlands) are currently investigating RAM's that can (or should) be used for assessing a decline in SOM.

5.3. Determination of SOM and SOC

The determination of SOM or SOC is a standard procedure. However despite the ubiquitous measurement there is no consensus on its definition (Carter, 2001). Discussion focuses on the fraction of organic matter that should or should not be included (fresh plant material versus decomposed organic matter, biomass or no biomass etc.).

SOM or SOC can be determined by destructive or non destructive methods. Depending on the nature of the method a quantitative of semi-quantitative result is obtained. Destructive methods use chemicals and/or heath to covert SOM or SOC in CO_2. There are multiple methods. Titrimetric, gravimetric, volumetric, spectophotometric or chromatographic techniques are currently used for carbon quantification (Schumacher, 2002).

The determination of SOM or SOC contents is performed by either:
Semi quantitative:

- Loss on ignition (LOI), most often (but not always) corrected for inorganic carbonates and clay percentage.
- Peroxide destruction

Quantitative

- wet oxidation followed by titration (dichromate Walkey and Black, 1934)
- wet oxidation followed by measurement of CO_2 evolution
- dry combustion and spectophotometric measurement (infrared) or thermal conductivity of evolved CO_2

The wet oxidation with dichromate of Walkey and Black is often used but several modifications have been used and still exists (Turin method (Kononova, 1966, Riehm and Ulrich, 1954)
SOM is calculated from LOI and the contents of clay, gypsum, iron(hydr)oxides and/or carbonates has to be taken into account. The temperatures during the determination of LOI differ (450-1100°C).
SOC is calculated from SOM. SOC = α * SOM with α a conversion term. The magnitude of α depends on the nature of the SOM. Tradionally α is 0,58 (Mebius, 1960, Kononova, 1958) but values from 1.724-2.5 (58-40%C) are reported (Nelson & Sommers, 1996).

Reviews and comparison of methods used for SOC determination have been prepared within the framework of ENVASSO (Spiegel, 2007; Hegymegi et al., 2007). Data on trends in SOM or SOC requires reliable and comparable analyses. Modelling of trends in SOM or SOC requires precise definition of SOM or SOC, their analytical methods for determination and bulk densities.

Lettens et al (2007) showed that the computation of SOM stocks without proper reference to uncertainties in SOM determination can lead to misconceived stock change for different land uses. Methods have been changed in the course of time. This might hamper trend analyses if new modified methods are used to assess SOM or SOC (Kalembasa and Jenkinson, 1973; Hammes et al, 2007; Jankauskas et al, 2006; Vos et al., 2007). Also changes in soil sampling and soil sample pre-treatment will add bias to trends and therefore impede data comparison.

The choice for a method to determine SOM or SOC depends of the composition of the soil sample (presence of carbonates, iron(hyr)oxides, gypsum, clay), the ease of use, costs, laboratory facilities and skills of the technicians, health, safety and environmental requirements.

The determination of the bulk density is – not yet – integrated in the monitoring systems of SOM or SOC. Stocks of SOM or SOC were mentioned in the questionnaires of the RAMSOIL-project by 7 countries (Belgium-Wallonia, Denmark, Finland, France, Germany, Slovak Republic, and Spain). Bulkdensities as part of a monitoring system to detect changes in stocks are not measured in the United Kingdom, Italy, Portugal, Greece, Poland, Sweden, Norway, Czech Republic, Lithuania and the Netherlands (Arrouys & Morvan, 2008). The determination of stocks of SOM or SOC is not further discussed in this deliverable.

5.4 Datasets of SOC or SOM

The only comprehensive source of data using a standardized classification is the FAO database at 1:1000000 (Morvan et al., 2008). At smaller scale national datasets are available, but are often weakly embedded in structural monitoring schemes (Morvan et al., 2008).

Information on the current state of organic carbon (SOC) in 13 EU countries (Austria, Bulgaria, Czech Republic, England & Wales, Greece, France, Ireland, Northern Ireland, Poland, Portugal, Scotland, Slovakia, and The Netherlands) is given by Arrouays and Morvan (2008). However these soil maps do not provide information on a change in SOM or SOC. On national scale information on changes in SOM or SOC are not available; however on regional scale analyses of datasets on changes in SOM or SOC have been published. Table 3 gives an overview of analyses of available datasets on changes in SOM or SOC in some of the EU-countries.

Datasets on changes in SOM or SOC differ in the layout of the sampling schemes, number of observations, soil layer thickness, method of analyses of SOM or SOC, frequency of sampling and period between sampling dates. There is no uniformity in datasets on changes in SOM or SOC. The layout of the sampling schemes and the analytical methods constrain in principle new sampling and analyses. However, changes in sampling schemes and analytical methods in time are not always taken into account.

At the European level there is a serious lack of geo-referenced, measured and harmonized data on soil organic carbon available from systematic sampling programmes (Panagos et al., 2006, p. 9). Even at a 300 km^2 scale (EMEP cells) there is not enough information for a complete European coverage. In southern European countries (Italy, Spain, and Greece), parts of Poland, Germany, the Baltic countries, Norway, Finland and France information is incomplete (Morvan et al., 2008). For 29 countries 33334 EMEP cell provides information on SOM or SOC; an additional 4147 cells are needed.

Jones et al. (2005) overcame this problem by using pedo-transfer rules (PTR) on existing, harmonized, data in the European Soil Database. The developed PTR (PTR 21) accounted for soil type, land use and climate. Although there results look promising (in achieving comparable data as measurements) they had to define 140 different conditions without any scope for effects of management (best practices) or soil use history.

The absence of such monitoring and data makes it very difficult for European countries to engage with soil management in the Kyoto Protocol obligations. JRC ISPRA has recently suggested a monitoring strategy for organic matter in soils across Europe (Stolbovoy et al., 2005, 2007a).

Though SOM or SOC contents are of considerable interest and can in principle be measured easily, there are few monitoring programs that allow systematic analyzing possible changes in SOC in agricultural land in practice (Janssens et al., 2005; Stolbovoy et al., 2005, Spiegel et al., 2007). Current estimates of changes in SOC at national and continental levels are therefore uncertain (Janssens et al., 2003).

In contrast to datasets on monitoring changes in SOM or SOC on cultivated agricultural soils, there is ample information derived from long-term soil experiments (LTSE). The European Soil Organic Matter Network (EuroSOMNET) provides information on 86 long-term field experiments in Europe (Smith et al., 1996). These long-term field experiments provide information on changes in SOM or SOC as affected by different management (fertilisers, soil amendments) and land use. Europe has the advantage of these long-term field experiments. The other continents have in total 34 long-term field experiments (http://www.rothamsted.bbsrc.ac.uk /aen/ somnet/index.htm). LTSE are difficult to initiate and sustain overtime; they require good organization, data management, and collaboration among scientists of several generations (Richter et al., 2007).
So far, most estimates are either derived from long-term field experiments (e.g., Jenkinson and Rayner, 1977; Wadman and de Haan, 1997) and/or simulation modelling (Jenkinson et al., 1987; Jenkinson, 1988; Yang and Janssens, 2000; Vleeshouwers and Verhagen, 2002; Freibauer et al., 2004; Vellinga et al, 2004; Smith et al., 2005).

6. Data processing

Data processing follows (geo) statistical analyses or modelling.

6.1. Observational research, statistical analyses

Design, sampling schemes and frequency of sampling determine the methods of (geo) statistical analyses. As these factors differ, there is no method of data processing that uniformly is used within the EU.

Data processing follows in general descriptive statistical analyses (means, medians, skewness and kurtosis) to enable a visualisation of possible trends. Paired two-sample Student's t-tests, sign and signranked tests, simple linear regression analysis, time serie analysis, principle components analyses are used amongst others to detect trends in means and medians over years. Descriptive statistical analyses are most often used but there is no general rule of thumb as design, sampling schemes and frequencies of sampling are not standardised. As data are often not normally distributed, non-parametric tests (example given Kruskal-Wallis) have to be used.

Resampling of (georeferenced) soil profiles (repeated soil surveys) are preceded by a selection of sites from a larger database. The criteria for this selection differ per region, soil type and landuse. The (geo) statistical analyses differ per database. A truly geostatistical analysis on the decline of SOM or SOC requires (semi) variogram(s) to quantify spatial variation of a regionalized SOM or SOC and changes heir in time. In Belgium and Ireland experiences one has gained experience with these geostatistical approaches (table 3). Very few have been conducted yet (Richter et al., 2007). It is beyond the reach of this deliverable for meticulous analyses of the geostatistical methods for analysing trends in SOM or SOC.

Table 3.First inventory of dDatasets of SOC or SOM in cultivated agricultural land (arable land and grassland) and non- cultivated land for the assessments of a decline in SOM or SOC collected within the RAMSOIL framework.

Country	*Depth (cm)*	*Method*^{1}	*Frequency*	*Spatial coverage*	*Reference*
Belgium	24		Annually^2	21000 samples y^{-1}	
Belgium, Flanders	0-24 cm	WB (modified)	1990, 1993, 1996, 1999	190000	Sleutel et al., 2003
Belgium, Flanders	ploughlayer	WB	1952,1990, 2003	116 locations	Sleutel et al., 2006
Belgium, South	Variable 7 databases	Variable (LOI, DC)	1990, 2000	Variable (16-11977)	Lettens et al., 2005
Belgium, Wallonia, southern part	variable	WB, 4/3	1955 (1950-1970) resampled in 2005	295	Goidts and Wesemael, 2007
Finland	Ploughlayer (~0-20 cm)	WB (1974)/DC	1974, 1987, 1998	Farmplots (2000, 1320, 705)	Sippola & Yli Halla, 2005
Germany	40	WB	Irregular, 1983, 1989, 1998	Farmplots	Nieder & Richter, 2000
Germany	0-120 cm (8 soil profile layers)	WB (modified)/DC	1969, 1996	Farmplots	Rinklebe & Makeschin, 2002
Ireland	10 (grassland)	WB	1964 a second sampling 1995-1996	678/220	Zhang et al., 2004
Netherlands	5 (grassland) 20 or 25 (arable land)	SOC≤12,%:KU (≤1994); DC (1994) DC (>1995) SOC>12.5%: LOI	1984-2004 Intervals 4-5 years	2-50 ha	Reijneveld et al., (accepted)
Netherlands	5 (grassland) 20 (maize land)	LOI/DC SOC≤12,%:KU (≤1994); DC (1994) DC (>1995) SOC>12.5%: LOI	1984-2004 Intervals 4-5 years	2-50 ha	Hanegraaf et al., 2008 (accepted)
Netherlands	Variable	SOC≤12,%:KU (≤1994); DC (1994) DC (>1995) SOC>12.5%: LOI	Irregular^2	2 -50 ha	Smit et al., 2007
Norway	Variable topsoil depth (1952)/0-20 cm.	Visual assessment (1952)/LOI	1952, 1976, 1986 and 2002	Farm, 25 ha	Riley & Bakkengard, 2006
Norway	0-25 cm	LOI	1991, 2001	291 Farmplots	Riley & Bakkengard, 2006

Sweden	0-25/25-60 cm(1956, 1984); 0-25, 25-35, 35-60 cm (2001)	WC (1956/1984 DC (2001)	1956, 1984, 2001	124 (1956), 65 (1984)124 (2001)	Kätterer et al., 2004
UK, England & Wales	0-15 cm	WB modified (%C<15 LOI (%C≥15)	1978-1983 first sampling; Second sampling 1994-1995 arable land; 1995-1996 grassland; 2003 non agricultural land	5661 (1st sampling); 853/971/535	Bellamy et al., 2005

[1] DC: dry combution followed by measuring CO_2, KU: Kumies, WB: Walkley & Black, LOI: Loss of ignition, [2] not each year at same place.

6.2. Modelling approaches

Cultivated lands can be managed in ways that either decrease SOC loss such as reducing tillage and using cover crops, or in ways that increase C inputs, such as incorporating crop residues or increasing manure application Cole et al. (1997).
Observational research is effective for prediction of future trends as long as the conditions under which the statistical equations have been derived do not change. This, however, is generally not the case. Changes in land use and management have occurred and will occur in the future. Also effects of climate change will lead to a change in conditions. Setting up new experiments or surveys is costly and results can only be obtained after a long time (years to decades). Most questions on effects of changes in landuse, management and climate can be answered using models (Richter et al., 2007; Willigen et al., 2008).

Models that can predict the decline in SOM (or SOC) are numerous. Within the SOMNET-framework 37 models have been identified of which 20 are developed by European research institutions (http://www.rothamsted.ac.uk/aen/somnet/intro.html). It is beyond the scope of this deliverable to discuss these models. The reader is referred to Smith et al, 1997; Pansu et al., 2007; Willigen et al., 2008.

Models differ in their description of SOM or SOC in soil. Simple models describe one quality of SOM or SOC (mono component). More complex models divide SOM or SOC in pools with different quality (multi-component) to which different rates of decomposition, mineralisation, assimilation and alteration are ascribed (Willigen and Neeteson, 1985, McGill, 1996, Willigen, 1991, Diekkrüger et al, 1995, Kersebaum et al (2005), Falloon et al., 2006; Willigen et al, 2008). The terminology given by Baldock(2006) on decomposition, mineralisation, assimilation and alteration of soil organic matter is used in this text: ”….*decomposition* refers to the removal of a given carbon substrate and is the sum of *mineralisation*, *assimilation* and *alteration*. *Mineralisation* is the release of carbon dioxide from biological respiration. *Assimilation* refers to the retention of substrate carbon by decomposer organisms as they synthesize cellular materials during growth. *Alteration* occurs when the chemical composition of an organic substrate is changed so that the remaining organic carbon is no longer identical to that present in the initial substrate.”
Multi-component models differ in the number of SOM or SOC pools and the method of pooling the soil processes mineralisation, assimilation and alteration and the rate determining factors.

Models differ in their ability to quantify effects of

- Scale (microsite -> catchment)
- Time (scales from minutes to centuries).
- Nutrient management (fertilisers, manure, soil amendments, timing)
- Crop management
- Soil management
- Weather conditions.

Models have been compared by Willigen and Neeteson (1985, six models), Willigen (1991, fourteen models), Diekkrüger et al. (1995, nineteen models), Powlson et al. (1996, seven (or 20 ?) models), Kersebaum et al. (2005, eighteen models).
Models that are used to forecast trends in SOM or SOC over decennia are for instance MINIP (monocomponent) and multicomponent models CENTURY, CESAR, DNDC, ANIMO, ROTh-C and CANDY (for other models see SOMNET database).

The multicomponent models describe kinetically defined pools of SOM or SOC and therefore calculate equilibrium levels under constant conditions. Although the magnitude of this equilibrium does not necessarily differ between models (Smith et al, (1997), the time needed to reach this equilibrium does differ (Willigen et al., 2008). The parameterisation of kinetically defined carbon pool models is questioned by Wutzler and Reichstein (2007) as the assumption that carbon stock is old soils are near steady state still accumulate carbon.
The mechanistical concept as well as the data-entry differ per model. Also the concept of the quality of SOM or SOC differs through including or excluding fresh organic matter from plant material. Models do differ in their ability to monitor SOM or SOC trends in time. There is yet no consensus which model serves best for modelling a decline in SOM or SOC. Options, if standardization is needed, are given by rather complex models as CENTURY, Roth-C or CANDY. Though these are complex models, they have gained wide acceptance through their flexibility to model soil processes for a variety of soil types, management and climate, through it’s soundness and predictions. The high flexibility provides a sound basis for analyzing current conditions and future scenario’s for a dynamic land use. Concluding, data processing can be harmonized by means of a mutual shared basic concept of dynamic equilibrium of SOM or SOC. Standardisation is possible by chosing rather straightforward by choosing one model or by synchronizing output data.

6.1 Data interpretation

Data interpretation of the decline of SOM or SOC uses a variety of factors. Soil typological unit (STU or soil type), soil texture (clay content), soil organic carbon (total and humus concentration) climate, topography and land cover. Table 4 gives an overview for these factors for the EU countries. Table 3 is based on the questionnaires.

Soil texture (clay content) and initial SOM or SOC content is mentioned by all correspondents. Landcover is also a factor that generally is used (exception Poland). STU is not used by Germany and Poland. Climate and topography are used for interpretation by UK, Denmark, Spain, Greece, Slovenia and Finland. France and Slovak republic uses topography for the interpretation of a decline SOM or SOC.
Stocks of SOM or SOC have been explicitly mention by France, Denmark, Spain, Finland, Slovak republic and Germany but other countries do not measure these stocks on a regular basis yet as bulkdensities are not included in monitoring networks.

Table 4. Factors used for interpretation a decline in SOM or SOC.

Country	Soil typological unit (STU)	Soil characteristics	Climate	Topography	La co

	(soil type)						
		Soil texture/clay content	Soil organic carbon (total and humus concentration)	Soil organic carbon stock			
United Kingdom	x	x	x		x	x	x
France	x	x	x	x		x	x
Denmark	x	x	x	x	x	x	x
Spain	x	x	x	x	x	x	x
Greece	x	x	x		x	x	x
Slovenia	x	x	x		x	x	x
Finland	x	x	x	x	x	x	x
Slovak republic	x	x	x	x		x	x
Belgium, Wallonia	x	x	x	x			x
Belgium, Flanders	x	x	x				x
German		x	x	x	x		x
Poland		x	x				

The evaluation of SOM or SOC contents in soil in the EU depends on the attributed indictor (function):

- Characteristic for a specific soil type developed on a given parent material.
- Soil health.
- Soil biodiversity indicator.
- Soil quality (biological, chemical and/or physical to sustain food quality and functionality.
- Soil fertility (biological, chemical and/or physical) to sustain food production.
- Soil degradation (erosion).
- Soil Carbon stock to combat greenhouse gasses emission.

One classifies the SOM or SOC contents. This classification depends on the attributed function.

Soil characteristic

The soil map of each EU country provides information on baselines of SOM or SOC contents. The information of these soil maps have been integrated for a European soil map on the scale 1:1,000,000. There is no overall coverage of the EU. Estimates of soil properties have been derived by use of pedotransfer rules (PTR). The Soil Profile Analytical Database for Europe SPADE 1 and SPADE-2 contains (estimated) data on SOC in the topsoil (0-30 cm) for important soil types (Van Camp et al., 2004). SOC have been calculated using PTR and classified in 4 classes (table 5). These SOC classes and estimates for SOC can only be used on a continental level through there scale and derivation by use of PTR.

Table 5. Classes of SOC of the toplayer 0-30 cm (Van Camp et al., 2004).

Class	SOC range
High	> 6.0%
Medium	2.1-6.0%
Low	1.1-2.0%
Very low	< 1.0%

Soil quality

The European Soil Database have classified soils of different groups of soil parent material and land use to provide both metainformation on available data and evaluation approaches for compiling background values of heavy metal and organic matter contents (Utermann et al., 2003, Van Camp et al, 2004). The 50 percentile values of SOM of these soils were classified by Van Camp et al (2004) into five classes (table 6).

Table 6. 50 percentile values of SOM (Van Camp et al, 2004).

Class	SOM mass, %	Classification (rating)
1	≤ 2	Low humus content
2	> 2-4	Middle humus content
3	> 4-8	High humus content
4	> 8-15	Very high humus content
5	> 15	Extremely high humus content

However these classifications differ per country. Examples given are the classifications for SOM in Slovakia (tabel 7) and Greece (table 8).

Table 7. Classification of soil types according to SOC content on topsoil in Slovakia (pers. comm. G. Barancikova, 2008).

Category	SOC, %	Soil types	Evaluation
I.	<1.5	Planosol, Luvisol and Regosol on arable land	Low
II.	3-1.5	Planosol on pasture, Cambisol, Rendzic Leptosol, Fluvisol ,Chernozem, Mollic Fluvisol on arable land	Medium
III.	>3	Ranker, Litic and Rendzic Leptosol, Podzol, Andosol and Cambisol on pasture	Good

Table 8. Indicative values of SOM classes in topsoil in Greece (pers. comm. S. Theocharopoulos and A. Papdopulos, 2007).

Category	SOM, %
Very poor	< 1
Poor	1-2
Average	2-3
Good	3-5
Rich	>5

The most common used threshold value for proper contents of soil organic matter is 2% SOC (~3.4 % SOM) and this value was also adopted by the EU as a starting value (Eckelmann et al., 2006). However, the first to come up with 2% were Greenland et al. (1975) and they developed this value as a threshold for soil structural stability, and not soil functioning, soil quality or other broader defined soil properties. Loveland and Webb (2003) made an extensive review on this – now widely accepted- threshold value of 2% and found that much 'evidence' was based on qualitative or –even worse- anecdotal data.

The quantification of a threshold value is very much related to the attibuted function of SOM or SOC. For most of these factors there is no or little quantitative data available and only for crop nutrition the potential yield may not be achieved when SOC decreases to values less than 1% (Loveland and Webb, 2003). Methods for deriving threshold values for maximum and lowest desirable SOC contents are given Sparling et al., 2003. They compared three approaches:

- statistical approach with maximum values derived from median and lowest values from lower quartiles;
- modelling approach with CENTURY with maximum values derived long term pasture and lowest values derived from an assumed recovery of 80% of the maximum values over a period of 25 years;
- an expert panel.

The magnitude of the threshold values derived from the statistical and modelling approaches were similar but the expert panel advised lower values. As lower quartiles are an arbitrary choice and did not have any ecological justification Sparling et al. (2003) modelling predictions were preferred.

Although there are numerous, well reported relations between SOC and various soil properties firm evidence of a threshold above or below which SOC contents hinder these properties is rare and a single critical threshold value for soil carbon content in temperate soils cannot be supported from the evidence available, which is also inadequate for the establishment of different critical SOC values for different soils under different land uses. And finally, Loveland and Webb (2003) conclude that 'the debate on SOM will continue, if for no other reason than almost everyone sees it as a keystone indicator for soil quality or soil 'health''.

Up till now the debate focuses on static threshold values based on information for a certain moment. However, this does not do justice to the dynamic nature of SOC degradation. Degradation of SOC is an essential part of the positive claims of SOC related to crop nutrition, but not for soil physical properties. Hence, in its nature it is not possible to have one single threshold value to cover all positive effects of SOM.

Moreover, SOC degradations are generally slow (compared to e.g. crop rotations) and therefore, more than the static value, the trend in time is an indicator for changing soil functioning.

Hence, from above we conclude:

1. There is too few quantitative data to unambiguously set a threshold value for SOC decline, although most authors report a value between 1% and 2%.
2. Soil organic carbon is beneficial for physical and chemical properties of soil. However, the inherent nature of chemical and physical properties makes it impossible to have one threshold value.
3. Up to now, the focus is on static threshold values whereas dynamic threshold values (i.e. threshold values that incorporate a trend, e.g. loss in kg C $ha^{-1}y^{-1}$) are more appropriate considering the slow response to changing conditions.

6.2 Risk perception

There are within the 27 EU countries no official RAM's on the soil threat on the decline of organic matter. RAM's as such are – clearly – not recognized yet. Nevertheless the debate on climate change and on soil degradation and loss of soil quality initiated scientific studies to changes in SOM or SOC in time and factors that act upon these changes. These changes which can be positive, negative or zero (steady state) and are depending on the system (climate - soil - landuse – management).

Fast and sizeable changes in SOM or SOC content and stock are brought about by erosion, deforestation, drainage of peat soils and change in land use (conversion of grassland in arable land). These impact forces form an acute risk on a decline of SOM or SOC content. Slow and small changes in SOM or SOC content (stock) in time are induced by agricultural management practices. It takes decades before significant differences of slow and small changes in SOM or SOC content (stock) can be established. This impact force forms a chronic risk on the decline of SOM or SOC.

As the impact and pressure of these different driving forces on the rate and magnitude of the change in SOM or SOC lead to different responses, risk assessment methodologies (RAM's) have to be adapted to these factors and the response on these factors (figure 2). Thresholds for minimum, optimal and maximum SOM or SOC contents (or stocks) in combination with the response are lacking. These threshold values depend on the function SOM or SOC is given and the impact factors that cause changes (figure 2). As systems (climate – soil - landuse – management) differ among EU countries and within a country it is conceivable that multiple tresholds are needed (Janzen et al., 1997). Task group 5 of the EU Thematic Strategy of Soil Protection anticipated a set of hundreds of target values (Van-Camp et al., 2004). At present it is not possible to define specific thresholds for RAM's. Ideally, regionally defined and validated thresholds would exist, but this is not the case at present. Research to establish regional thresholds is a priority (Eckelmann et al., 2006).

RAM's have to be developed. Comprehensive and comparable data for EU27 on SOM or SOC content are not available yet but models (PTR's) exist to estimate it (EU commission, 2006). The soil map of EU of 1:1,000,000 is based on PTR's. A logical start is to use current soil monitoring systems of individual EU-countries. Soil monitoring systems (SMN's) are currently used or are implemented in two third of the EU-countries. Methodologies for assessing a change in SOM or SOC content or stock in the EU differ in datagathering, dataprocessing, datainterpretation and riskperception. Differences are brought about by the national or region systems of soil mapping, scale, sampling method, physico-chemical analytical methods, dataprocessing and use of biophysical models. There is no uniform standarised accepted method for assessing changes in SOM or SOC contents and stocks yet but Eckelmann et al. (2006) and Stolbovoy et al (2005, 2006, 2007a, 2007b) proposed protocols for respectively datarequirement and data gathering and dataprocessing to arrive to comprehensive and comparable data on SOM or SOC contents and stock in European soils. However SMN's are questioned as tools for measuring annual changes in C sinks in national accounting of greenhouse gasses (Saby et al, 2008).

Next, with soil biophysical models threshold values can be derived for impact factors and forecasts of trends in SOM or SOC can be made (Eckelmann et al., 2006). Thresholds will depend on the target: i.e. soil health, sustainable crop production, prevention of erosion, prevention of landslides. There is debate on these tresholdvalues for risk assessment and baseline values for identication of characteristic enties (example given a specific soil type).

Driving forces	Natural forces - Climate - Topography - Soil parent material - Erosion - Vegetation cover Human induced forces - Land use (cultivation, farming system, conversion) - Land management (grazing, crop rotation, soil tillage) - Land degradation (deforestation, fire, desertification)	***Response*** *Water quality and resources:* improved soil structure, and increased infiltration and waterholding and capacity of the soil, leading to better recharge of groundwater aquifers and improved water quality and reduced desertification. *Soil protection:* optimum SOM content leads to improved soil fertility and soil structure and reduced wind erosion. *Climate:* improved carbon sequestration, contributing to mitigate climate change impacts
Pressure	- Carbon sequestration - Soil fertility - Pollutant transfer	

	- Sustainable crop production - Water availability - Infiltration - Biodiversity - Infrastructure	*Renewable or non-renewable resources:* minimum tillage leads to reduced use of fossil fuel. *Biodiversity, flora, fauna:* increased biological activity and possibly improved soil biodiversity and soil health. *Likelihood or scale of environmental risks:* due to reduction of soil vulnerability to erosion, the risk of floods and landslides will diminish.
State	- SOM or SOC (%, stock)	
Impact	- Soil structure - Waterholding capacity - Stock SOC - Nutrient availability in time and space - Sustainability - multifunctionality - Soil health	

Figure 2. DPSI-R scheme (***D**river, **P**ressure, **S**tate, **I**mpact and **R**esponse*) for decline in SOM or SOC (adapted from EU Commission, 2006).

Areas at risk (hotspots) have been identified by Van-Camp et al. (2004). Hotspots were characterized by climate, physiography and landuse history. Four areas were distinguished: Northern subboreal Europe (acidification, drainage of peatland, fire), Mediterranean (desertification, fire, deforestation shallow soils, land use change), sites in the proximity of intensive agriculture (ammoniumvolatilisation) and alpine soils (climate change). It is expected that tresholdvalues for risk on SOM or SOC decline differ per hotspot and driving factor.

Information on assessment methodologies on the decline of SOM or SOC is widely available (table 3) but information on risk assessment methodologies on soil organic matter decline is not. This attributed to the poor recognition of the threat and the lack of referenced values for tresholds and impact factors. The questionnaires gave general information on the assessment methodology; no information was forwarded on the risk assessment. This hampers the outcome of this deliverable.

Although the assessment methodologies are in general simple (resampling georeferenced soil profiles, soil fertility surveys, chronosequences), the scale and the intensity (resolution) and dataprocessing restrain SMN's. Especially when high spatial and temporal variability lays a constrain on the assessment of a decline in SOM or SOC as this requires intensive and expensive research. The lack of referenced thresholds for specific effects of impact factors inhibits an (cost) efficiency development of SMN's. A known threshold value can lead to a more cost-efficient RAM through adaptation of sampling schemes, sampling size, sampling frequency and choice of the analytical method.

Biophysical models contribute greatly to the insight on the decline of SOM or SOC. The effect of impact factors can qualitative and quantitative be assessed. Biophysical models are essential for deriving treshold values. There are still major challenges to combat. Current SOM or SOC contents partly reflect current land-use. When deriving threshold values or forecasting trends in SOM or SOC a distinction between the portion that is not related to the present land-use. Also, it is not clear how this portion is affected by current land-use. Options, if standardisation is needed, are given by rather complex models as CENTURY, Roth-C or CANDY. Though these are complex models, they have gained wide acceptance through their flexibility to model soil processes for a variety of soil types, management and climate, through it's soundness and predictions. The high flexibility provides a sound basis for analyzing current conditions and future scenario's for a dynamic land use.

6.3 Conclusion

Past long-term experimental studies have shown that SOM or SOC is highly sensitive to changes in land use, with changes from native ecosystems such as forest to agricultural systems almost always resulting in a loss of SOC (Jenkinson 1977, Paul et al. 1997). Likewise, the way in which land is managed following land use change has also been shown to affect SOM or SOC contents and stocks. We therefore have the opportunity in the future to change to land use and land management strategies that lead to C storage in the soil, thereby mitigating effects of greenhouse gasses (GHGs) and improving soil fertility.

Jones et al. (2005) wrote 'There is an urgent need for harmonization of soil organic carbon monitoring networks'. This statement refers to the first step (data gathering) of the risk chain. From the results presented above, however, there seems to be as much an urgent need for the development of threshold values and the perception of risks. For data gathering and data processing we see little obstacles for harmonization and, as threshold values and risk perception, still largely need to be developed, harmonization can be easily introduced. Hence, for soil organic matter there are good options for harmonization, when the developments in threshold values and risk perception are properly coordinated (e.g. performed in EU actions).

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