FINAL REPORT

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"REVIEW OF EXISTING INFORMATION ON THE INTERRELATIONS BETWEEN SOIL AND CLIMATE CHANGE"

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CLIMATE CHANGE SOIL CARBON

Key messages

1. *Carbon stock in EU soils* – The soil carbon stocks in the EU27 are around 75 billion tonnes of carbon (C); of this stock around 50% is located in Sweden, Finland and the United Kingdom (because of the vast area of peatlands in these countries) and approximately 20% is in peatlands, mainly in countries in the northern part of Europe. The rest is in mineral soils, again the higher amount being in northern Europe.
2. *Soils sink or source for CO_2 in the EU* – Both uptake of carbon dioxide (CO_2) through photosynthesis and plant growth and loss of CO_2 through decomposition of organic matter from terrestrial ecosystems are significant fluxes in Europe. Yet, the net terrestrial carbon fluxes are typically 5-10 times smaller relative to the emissions from use of fossil fuel of 4000 Mt CO_2 per year.
3. *Peat and organic soils* - The largest emissions of CO_2 from soils are resulting from land use change and especially drainage of organic soils and amount to 20-40 tonnes of CO_2 per hectare per year. The most effective option to manage soil carbon in order to mitigate climate change is to preserve existing stocks in soils, and especially the large stocks in peat and other soils with a high content of organic matter.
4. *Land use and soil carbon* – Land use and land use change significantly affects soil carbon stocks. On average, soils in Europe are most likely to be accumulating carbon on a net basis with a sink for carbon in soils under grassland and forest (from 0 - 100 billion tonnes of carbon per year) and a smaller source for carbon from soils under arable land (from 10 - 40 billion tonnes of carbon per year). Soil carbon losses occur when grasslands, managed forest lands or native ecosystems are converted to croplands and vice versa carbon stocks increase, albeit it slower, following conversion of cropland.
5. *Soil management and soil carbon* – Soil management has a large impact on soil carbon. Measures directed towards effective management of soil carbon are available and identified, and many of these are feasible and relatively inexpensive to implement. Management for lower nitrogen (N) emissions and lower C emissions is a useful approach to prevent trade off and swapping of emissions between the greenhouse gases CO_2, methane (CH_4) and nitrous oxide (N_2O).
6. *Carbon sequestration* – Even though effective in reducing or slowing the build up of CO_2 in the atmosphere, soil carbon sequestration is surely no ‘golden bullet’ alone to fight climate change due to the limited magnitude of its effect and its potential reversibility; it could, nevertheless, play an important role in climate mitigation alongside other measures, especially because of its immediate availability and relative low cost for 'buying' us time.
7. *Effects of climate change on soil carbon pools* – Climate change is expected to have an impact on soil carbon in the longer term, but far less an impact than does land use change, land use and land management. We have not found strong and clear evidence for either overall and combined positive of negative impact of climate change (atmospheric CO_2, temperature, precipitation) on soil carbon stocks. Due to the relatively large gross exchange of CO_2 between atmosphere and soils and the significant stocks of carbon in soils, relatively small changes in these large and opposing fluxes of CO_2, i.e. as result of land use (change), land management and climate change, may have significant impact on our climate and on soil quality.

8. *Monitoring systems for changes in soil carbon* – Currently, monitoring and knowledge on land use and land use change in EU27 is inadequate for accurate calculation of changes in soil carbon contents. Systematic and harmonized monitoring across EU27 and across relevant land uses would allow for adequate representation of changes in soil carbon in reporting emissions from soils and sequestration in soils to the UNFCCC.
9. *EU policies and soil carbon* – Environmental requirements under the Cross Compliance requirement of CAP is an instrument that may be used to maintain SOC. Neither measures under UNFCCC nor those mentioned in the proposed Soil Framework Directive are expected to adversely impact soil C. EU policy on renewable energy is not necessarily a guarantee for appropriate (soil) carbon management.

Executive summary

The European Commission has recently adopted the Thematic Strategy for soil protection (COM(2006)231 final), with the objective to ensure that Europe's soils remain healthy and capable of supporting human activities and ecosystems. Climate change is identified as a common element in many soil threats. Therefore the Commission intends to assess the actual contribution of the protection of soil to climate change mitigation and the effects of climate change on soil productivity and the possible depletion of soil organic matter as result of climate change. The objective of this study is to provide a state of the art and more robust understanding of interactions between soil under different land uses and climate change than is available now, through a comprehensive literature review and expert judgment.

1 Carbon stock in EU soils
The amount of carbon in European soils is estimated to be equal to 73 to 79 billion tonnes. These estimates are based on applying a common methodology across Europe, the larger estimate was based on a method developed by the Joint Research Centre of the European Commission and the smaller estimate on a soil organic carbon (SOC) map of the United States Department of Agriculture. These two methodologies gave similar estimates for most of the European countries. The estimates were of the same order of magnitude as national estimates based on national methodologies and are therefore deemed reliable.
Carbon in EU27 soils is concentrated in specific regions: roughly 50% of the total carbon stock is located in Sweden, Finland and the United Kingdom (because of the vast area of peatlands in these countries) and approximately 20% of the carbon stock is in peatlands mainly in the northern parts of Europe. The rest of soil C is in mineral soils, again the higher amount being in northern Europe.

2 Soils sink or source for CO_2 in the EU
Uptake of carbon dioxide (CO_2) through photosynthesis and plant growth and loss (decomposition) of organic matter from terrestrial ecosystems are both significant fluxes in Europe. Yet, the net terrestrial carbon fluxes (uptake of CO_2 minus respiration by vegetation and soils) are typically smaller relative to the emissions from use of fossil fuel. The current changes in the carbon pool of the European soils were estimated from different studies using different methods, by land use category using models that simulate carbon cycling in soil. The results of the different studies deviated considerably from each other, and all results were accompanied with wide uncertainty ranges. Some studies on the basis of measurements in UK, Belgium and France on soil carbon over longer periods show losses of carbon especially from cropland; other studies from the UK and from the Netherlands show no change or increases in soil carbon stocks over time.
Grassland soils were found in all studies to generally accumulate carbon. However, the studies differ on the amount of carbon accumulated. In one study, the sink estimate ranged from 1 to 45 million tonnes of carbon per year and, in another study, the mean estimate was 101 million tonnes per year, although with a high uncertainty.
Cropland generally acts as a carbon source, although existing estimates vary highly. In one study, the carbon balance estimates of croplands ranged from a carbon sink equal to

10 million tonnes of carbon per year to a carbon source equal to 39 million tonnes per year. In another study, croplands in Europe were estimated to be losing carbon up to 300 million tonnes per year. The latter is now perceived as a gross overestimation.

Forest soils generally accumulate carbon in each European country. Estimates range from 17 to 39 million tonnes of carbon per year with an average of 26 million tonnes per year in 1990 and to an average of 38 million tons of carbon per year in 2005.

It would seem that on a net basis, soils in Europe are on average most likely accumulating carbon. However, given the very high uncertainties in the estimates for cropland and grassland, it would not seem accurate and sound to try to use them to aggregate the data and produce an estimate of the carbon accumulation and total carbon balance in European soils.

3 Peat and organic soils

The current area of peat occurrence in the EU Member States and Candidate Countries is over 318 000 km^2. More than 50% of this surface is in just a few northern European countries (Norway, Finland, Sweden, United Kingdom); the remainder in Ireland, Poland and Baltic states. Of that area, approximately 50% has already been drained, while most of the undrained areas are in Finland and Sweden.

Although there are gaps in information on land use in peatlands, it can be estimated that water saturated organic rich soil (peatland) have been drained for:

- agriculture – more than 65 000 km^2 (20% of the total European peatland area);
- forestry – almost 90 000 km^2 (28%);
- peat extraction – only 2 273 km^2 (0.7%).

This is important as the largest emissions of CO_2 from soils are resulting from land use change and related drainage of organic soils and amount to 20-40 tonnes of CO_2 per hectare per year. The emission from cultivated and drained organic soils in EU27 is approximately 100 Mt CO_2 per year. Peat layer have been lost by oxidation during land use, but the estimate derivable from the published data, ca. 18 000 km^2, is very probably an underestimate.

4 Land use and soil carbon

Monitoring programs, long term experiments and modelling studies all show that land use significantly affects soil carbon stocks. Soil carbon losses occur when grasslands, managed forest lands or native ecosystems are converted to croplands. Vice versa soil carbon stocks are restored when croplands are either converted to grasslands, forest lands or natural ecosystems. Conversion of forest lands into grasslands does not affect soil carbon in all cases, but does reduce total ecosystem carbon due to the removal of aboveground biomass.

The more carbon is present on the soil, the higher the potential for losing it. Therefore the potential losses of unfavourable land use changes on highly organic peat soils are a major risk. The most effective strategy to prevent global soil carbon loss would be to halt land conversion to cropland, but this may conflict with growing global food demand unless per-area productivity of the cropland continues to grow.

5 Soil management and soil carbon

Soil management practices are an important tool to affect the soil carbon stocks. Suitable soil management strategies have been identified within all different land use categories and are available and feasible to implement. These are:

- On **cropland**, soil carbon stocks can be increased by
  (i) agronomic measures that increase the return of biomass carbon to the soil,
  (ii) tillage and residue management,
  (iii) water management,
  (iv) agro-forestry.
- On **grassland**, soil carbon stocks are affected by
  (i) grazing intensity
  (ii) grassland productivity,
  (iii) fire management and
  (iv) species management.
- On **forest lands**, soil carbon stocks can be increased by
  (i) species selection,
  (ii) stand management,
  (iii) minimal site preparation,
  (iv) tending and weed control,
  (v) increased productivity,
  (vi) protection against disturbances and
  (vii) prevention of harvest residue removal.
- On **cultivated peat soils** the loss of soil carbon can be reduced by
  (i) higher ground water tables.
- On **less intensively / un-managed heathlands and peatlands**, soil carbon stocks are affected by
  (i) water table (drainage),
  (ii) pH (liming), fertilisation,
  (iii) burning
  (iv) grazing.
- On **degraded lands**, carbon stocks can be increased after restoration to a productive situation.

Given that land use change is often driven by demand and short term economic revenues, the most realistic option to improve soil carbon stocks is to a) protect the carbon stocks in highly organic soils such as peats mostly in northern Europe, and b) to improve the way in which the land is managed to maximise carbon returns to the soil and minimise carbon losses. Increased nitrogen fertilizer use has made a large contribution to the growth in productivity, but further increased use will lead to greater emissions of nitrous oxide (N_2O). Hence future emphasis should be concentrated on the other main driver of productivity, i.e. improved crop varieties.

6 Carbon sequestration

Soils contain about three times the amount of carbon globally as vegetation, and about twice that in the atmosphere. There is a significant and large uncertainty associated with the response of soil carbon (and other pools of biospheric carbon) to future climate changes. Most response are calculated with simulation models with some models

predicting large releases of additional carbon from soils and vegetation under climate change, and others suggesting only small feedback. The maximum possible amount of carbon that soil sequestration could achieve is about one third of the current yearly increase in atmospheric carbon (as carbon dioxide) stocks. This is about one seventh of yearly anthropogenic carbon emissions of 7500 Mt C. In Europe emissions of greenhouse gases amount to approximately 4100 Mt CO_2 (or 1000 Mt C) per year.
Today, soils in Europe are most likely a sink and the best estimate is that they sequester up to 100 Mton C per year. Higher sequestration is possible with adequate soil management. Soil C-sequestration alone is surely no 'golden bullet' to fight climate change but is it realistic to link climate change with soil carbon conservation, as soil carbon sequestration is cost competitive, of immediate availability, does not require the development of new and unproven technologies, and provides comparable mitigation potential to that available in other sectors.
Therefore, given that climate change needs to be tackled urgently if atmospheric carbon dioxide concentrations are to be stabilized below levels thought to be irreversible, soil carbon sequestration or the even more effective conservation of current carbon stocks in soils has a key role to play in any raft of measures used to tackle climate change.

7 Effects of climate change on soil carbon pools

We have not found strong and clear evidence for either an overall combined positive or negative impact of climate change (raised atmospheric CO_2 concentration, temperature, precipitation) on terrestrial carbon stocks. There are suggestions for enhancing soil C stocks at higher atmospheric CO_2 concentration and reducing soil C stocks when temperatures are rising. Most studies have taken moderate changes in temperature increases and sudden and more severe changes in temperature of precipitation have not been considered, as the management of land and soils overrules any impact on soil carbon from climate change.
All of the factors of climate change (raised atmospheric CO_2 concentration, temperature, precipitation) affect soil C, with the effect on soils of CO_2 being indirect (through photosynthesis) and the effects of weather factors being both direct and indirect. Climate change affects soil carbon pools by affecting each of the processes in the C-cycle: photosynthetic C-assimilation, litter fall, decomposition, surface erosion, hydrological transport. Due to the relatively large gross exchange of CO_2 between atmosphere and soils and the significant stocks of carbon in soils, relatively small changes in these large but opposing fluxes of CO_2 may have significant impact on our climate and on soil quality. Therefore, managing these fluxes (through proper soil management) can help mitigate climate change considerably.

8 Monitoring systems for changes in soil carbon

Today, monitoring and knowledge on land use and land use change in EU27 is insufficient, yet land use and land use change are a key source of greenhouse gas emissions in many of the EU27 member states. Soil monitoring in EU27 seems like the Tower of Babel: countries tend to have their own systems, if any, sometimes even more than one system, and the results are not fully compatible across EU27. The few existing systems tend to have been set up for different purposes, often not including that of providing evidence concerning the impact of climate change on soil carbon pools. This

lack of systematic and comparable data gathering and analyses seriously hampers any attempt to provide reliable, EU-wide data on the soil carbon stock and changes therein.
Moreover, the new goal of monitoring stock-changes rather than stock-magnitudes may necessitate significant changes to current soil sampling procedures.
Given the lack of reliable national monitoring systems and without an EU wide harmonized system of monitoring of soil carbon in place, it would be a significant advance if the EU were to ask for a design or initiate implementation of a harmonized EU27 monitoring for land uses and for specific activities that affect soil carbon stocks and emissions of CO_2. Such monitoring would also allow for adequate representation of changes in soil carbon in EU27 in reporting to the United Nations Framework Convention to Combat Climate Change (UNFCCC).

9 EU policies and soil carbon

We have critically reviewed EU policies that are likely to have impacts on soil carbon (C) to assess whether any of those policies might have adverse impacts on soil C in the long term. Policies reviewed were the Common Agricultural Policy (CAP), the Nitrates Directive, the Renewable Energy Sources Directive, the Biofuels Directive, Waste policy and the EU Thematic Strategy for soil protection.
Legislation to encourage the production of arable crops to provide feed stocks for renewable energy is perhaps the legislation most likely to lead to decreases in the overall carbon content of European soils. While studies may indicate much of the demand may be met by imports from outside the EU, and hence may have little impacts on soil C within the EU, there may be serious implications for soil C stocks in those countries which supply renewable energy or their substrates.
We conclude that the need to comply with environmental requirements under the Cross Compliance requirement of CAP is an instrument that may be used to maintain SOC. The measures required under UNFCCC are not likely to adversely impact soil C. Nor are there any measures in the proposed Soil Framework Directive that would be expected to lead to decreases on soil C.