# European Climate Change Programme (ECCP)

# Working Group on Sinks Related to Agricultural Soils

**Executive Summary**

## 1 Introduction

Measures to enhance carbon sequestration in agricultural soils are potential tools for mitigating global warming as well as enhancing soil protection. There is evidence that under current agricultural practices, many European soils are losing organic carbon and thus constitute sources of atmospheric $CO_2$ rather than sinks. This may be the case for arable cropping systems, which have tended towards greater specialisation and monoculture, and for farmed organic soils, such as peat lands. Farming practices have an important impact on soil carbon content. Thus, there is a potential for carbon sequestration as well as for a reduction of greenhouse gas emissions from soils.

Carbon sequestration in agricultural soils is accountable under Article 3.4 of the Kyoto Protocol which covers additional human-induced activities related to changes in greenhouse gas emissions and removals by sinks in agricultural soils and the land-use change and forestry categories. The Bonn Agreement formulated at COP6bis in July 2001 clarifies the implementation of Article 3.4 as follows: In the context of agriculture, eligible activities comprise "cropland management", "grazing land management" and "revegetation" provided that these activities have occurred since 1990, and are human-induced. The Marrakech Accord agreed at COP7 in November 2001 sets legally binding guidelines for reporting and accounting for agricultural carbon sinks. Thus, carbon sequestration in agricultural soils is a potentially suitable mechanism to ensure compliance with the EU’s obligation to cut its greenhouse gas emissions.

## 2 Objective of the Working Group

The European Climate Change Programme (ECCP) Working Group on Sinks Related to Agricultural Soils (“WG Soils”) had the general objective of estimating the carbon sequestration potential of agricultural land in the EU. To this aim technical measures for carbon sequestration in agricultural soils were analysed with respect to their sequestration potential as well as their environmental and their socio-economic impact. The work of the WG Soils provides the technical background analysis that should enable the Commission to propose, if appropriate, policy instruments aiming at carbon sequestration in agricultural soils to the Council and the European Parliament. Furthermore, as organic carbon is an important issue in connection with soil functions, such as soil fertility, stability, structure and water storage capacity, the group made the link between carbon sequestration and the broader aspects of soil protection.

# 3 Overall potential for GHG mitigation

According to the estimates provided by the experts, there is the potential to sequester up to 60-70 Mt $CO_2$ $y^{-1}$ in agricultural soils of EU-15 during the first commitment period, which is equivalent to 1.5-1.7 % of the EU's anthropogenic $CO_2$ emissions.

This amount of 60-70 Mt $CO_2$ $y^{-1}$ would make up 19-21% of the total reduction of 337 Mt $CO_2$ $y^{-1}$ to which the EU is committed during that period.

# 4 Specific measures

Soil carbon sequestration is the uptake of atmospheric carbon and its storage in the soil. This report analyses measures aiming at an increase of soil carbon as well as at a reduction of its loss. Increasing the soil carbon content in agricultural soils can be achieved by increasing the carbon input, decreasing the output or a combination of the two. Possible changes of emissions of $N_2O$ and $CH_4$, which are both powerful greenhouse gases, are important when determining the overall mitigation effect of a given activity.

Carbon sequestration measures considered by the IPCC in the Special Report on Land Use, Land Use Change and Forestry (LULUCF), which are analysed here, include cropland management to provide higher carbon inputs to the soil, irrigation water management, conservation tillage, erosion-control practices, grazing management, protected grassland / set-aside, grassland productivity improvements, and fire management in grasslands. As this report is concerned with agricultural soils, further aspects, such as forest management and revegetation (except on set-aside land) are not considered further here. The report concentrates on cropland and grassland management, though organic soils, such as peat lands, are also considered where they are used for agriculture. Management changes within a single land-use (e.g. reduced tillage on cropland), as well as transitions between land-uses (e.g. cropland to grassland conversion) are considered.

Carbon sequestration can occur either through a reduction in soil disturbance (since more carbon is lost as $CO_2$ from tilled soils than soils that are less disturbed) or through increasing the carbon input to the soil. It is important to maintain existing carbon stocks and slow soil carbon loss through improved management practices.

Table 1 Most promising carbon sequestration measures

| | Technical measure | Sequestration Potential per unit area [t $CO_2$ $ha^{-1}$ $y^{-1}$] | Potential in EU-15 during first commitment period[1] [Mt $CO_2$ $y^{-1}$] | Environmental side effects | Impact on farm income |
|---|---|---|---|---|---|
| 1 | Promote organic input on arable land (crop residues, cover crops, farm yard manure, compost, sewage sludge) | 1-3 | 20 | Chemical fertiliser can be partly replaced, leading to reduced $N_2O$ emission and reduced nitrate leaching. Accounting of additional nitrogen input is required to avoid nitrogen overdose and nitrate losses. Erosion control and reduced nitrate leaching under cover crops. Danger of contamination by heavy metals and other pollutants, as well as biosafety issues, are controlled under Community and national legislation. Reduced pathogen risk from composted material. | Positive long-term tendency due to better soil fertility. Easy implementation, but potentially higher costs due to transport and purchase of organic material and compost production. On-farm composting can provide an additional source of income. Capital and operational costs incurred by setting up a composting facility at farm level may be offset by (1) a fee for taking organic waste (2) income from selling compost (3) savings in fertiliser, water consumption, disease suppression. |
| 2 | Permanent revegetation of arable set-aside land (e.g. afforestation) or extensivation of arable production by introduction of perennial components | 2-7 | 15 | Benefits for wildlife, biodiversity, and landscape. | Regionally specific, positive only if linked to compensation payment for nature protection. |
| 3 | Biofuel production with short-rotation coppice plantations and perennial grasses | 2-7 | 15 | **The benefit from substitution of fossil fuels by bioenergy is much greater than the effect from carbon sequestration.** | Regionally specific, potentially positive if linked to subsidies or emerging markets |
| 4 | Promote organic farming | >0-2 | 14 | Benefits for wildlife, biodiversity, landscape, but unclear whether there is a risk of higher $N_2O$ emission from incorporation of legume residues. More research is needed here. | Potentially positive due to higher prices for organic products, and support under national RDPs for conversion to organic farming, and to some extent, organic production. Market share is growing. However, lower yields per ha, compared to conventional farming. |

[1] For the estimation of the sequestration potential in the EU-15, the sequestration potential per unit area was taken into account as well as the area suitable for each measure and other limiting factors. Finally, from an overall potential the potential during the first commitment period was estimated considering economic factors.

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|---|---|---|---|---|---|
| 5 | Promote permanently shallow water table in farmed peat land | 5-15 | 15 | Benefits for wildlife, biodiversity, landscape, water retention, reduced $N_2O$ emissions. | Regionally specific, positive only if linked to compensation payment for nature protection. Some peat lands form the most productive agricultural areas in England. |
| 6 | Zero tillage or reduced tillage | >0-3 | <9 | In some regions a suitable instrument for erosion control and soil conservation. Soil structure improves under most conditions, but increased bulk density may lead to reduced rootability and infiltration in some cases. Zero and reduced tillage can lead to higher $N_2O$ emission and more pesticide use, especially under wet soil conditions. Very small carbon sink in reduced tillage systems. | Site and region specific, possible increased production risks for farmer. Positive only if linked to good erosion control and better soil fertility. Lower labour requirements and operating costs (e.g. lower fuel consumption) have led to an adoption of conservation tillage in a number of large farms. Capital costs involved in investment in equipment for conversion from conventional tillage. |

Please note that the figures for the sequestration potential are in general not additive.

Measures with a positive carbon sequestration include (see Table 1 for most promising measures):

- Zero tillage systems, which represent an extreme form of cropland management in which any form of mechanical soil disturbance is continuously abandoned except for shallow opening of the soil for seeding, like continuous mulch-seed or direct-drill. In reduced tillage systems soil disturbance is kept at a minimum or is reduced as compared to conventional plough systems. This measure includes a wide range of different practices depending on various climate and soil conditions. The sequestration rate as well as the potential environmental and socio-economic impacts can thus only be estimated qualitatively, in comparison to zero tillage.
- A better use of animal manure, crop residues, sewage sludge or compost, by applying the available material on cropland instead of on grassland or elsewhere as it is common practice. This measure requires some transport of manure from regions of intensive animal production to suitable crop lands. The widespread production of compostable waste limits the distance between production and application sites of compost in most cases as well as transportation costs.
- Improved rotations with higher carbon inputs to the soil;
- Switching from conventional arable agriculture to other land-uses with higher carbon inputs or reduced disturbance:
    - Bioenergy crop production with perennial herbaceous and woody species only. Considered here is only the carbon sequestration effect, which is much smaller than the beneficial effect resulting from fossil fuel replacement. In annual bioenergy plants (e.g. rape for biodiesel, sugar beet for bioethanol) carbon sequestration in the soil is not enhanced.
    - Set-aside land;

- Conversion of arable land to grassland. This option includes the possibility to expand field margins, on which grass should be grown, and possibly shrubs or trees.
- Conversion of arable land to woodland (afforestation);
- Allowing natural regeneration to occur;
- Extensification, implying extending the crop rotations and including more intercrops and grasses in order to increase the carbon input to the soil;
- Organic farming.

Measures considered with a smaller or no potential include:

- Cultivation of perennial crops;
- Increased fertilisation;
- Increased irrigation;
- Changes in livestock management to increase productivity.

Increased yields in the past have not produced higher input of carbon in the soil. In contrast, increases in yields were mainly achieved via changes in the harvest index. So, while grain yields increased, the amount of crop residue was even reduced.

# 5 Limitation for the application of sequestration measures

## 5.1 Regional differences in carbon sequestration:

The carbon sequestration values in Table 1 were derived for average European arable soils. Generally an analysis of the overall carbon sequestration potential of particular measures as well as their potential environmental and socio-economic impacts is limited by strong regional differences, which are due to regional variation in soil types and climate. Whilst some soils (e.g. clay soils) accumulate carbon relatively quickly, others (e.g. sandy soils) may accumulate practically no carbon even after 100 years of high carbon inputs. Similarly, soils in colder climates, where decomposition is slowed by low temperature, may accumulate carbon more rapidly than soils in warmer climates where decomposition is faster. Furthermore, the potential for sequestration is higher in soils with low organic carbon content and decreases in soils with higher organic carbon content.

In the same way do environmental side effects of soil carbon sequestration measures depend on the soil type. The actions that could be foreseen for some kinds of soils, for example the use of sewage sludge, can give varying results according to the type of soil (i.e. mainly due to the texture, permeability, level of the groundwater table, etc.). Reduced tillage may lead to problems of weed control under wet conditions, implying high herbicide applications and potential groundwater pollution, while this problem may be less severe in dryer regions. In most cases, reduced tillage and no-tillage will improve the soil structure, but it may also lead to soil compaction under certain soil conditions, rendering this measure not suitable in some regions.

It is thus not possible to give an overall evaluation for a single action or treatment without taking into account the climate and soil. Generally, management practices also vary from place to place, with the most important for carbon sequestration being soil management / tillage and the use of organic manure and sewage sludge. At a European scale insufficient information is available on regional variation in management practices.

## 5.2 Sink saturation

Whilst the figures given in Table 1 are approximate for a short period (e.g. a 5 year Kyoto Commitment Period), changes in carbon sequestration need to be considered also over a longer time horizon. Soil carbon sequestration is non-linear. Long-term experiments show that increases in soil carbon are often greatest soon after a land-use / land-management change is implemented. As the soil reaches a new equilibrium, the rate of change decreases, so that after between 20 and 100 years a new equilibrium is reached and no further change takes place. This phenomenon is sometimes referred to as sink saturation. Whilst soil carbon levels may not reach a new equilibrium until 100 years after land-use / land-management change, the carbon sequestration potential may already be minimal after 20 years; 20 years is the value used by the IPCC for national greenhouse gas inventories. Soil carbon sequestration does not, therefore, have limitless potential to offset $CO_2$ emissions; the yearly benefits will continue for about 20 years, but in a degressive way.

## 5.3 Non-permanence

Soil carbon sequestered in arable soils may be non-permanent. By reverting to old agricultural management or land-use practice, soil carbon is lost more rapidly than it accumulated. For soil carbon sequestration to occur, the land-use / land-management change must also be permanent. Whilst agricultural soils that are tilled every few years may contain more carbon than the same soils cultivated every year, much of the benefit of reduced tillage is lost by ploughing, when compared to a permanent management change. For practical purposes, therefore, in order to implement a meaningful carbon sequestration policy on agricultural land, management changes must be permanent.

## 5.4 Cost-effectiveness

If a sequestration measure is associated with a cost higher than conventional agricultural practice, and this cost is assumed to be constant throughout the period of application of this measure, the issues of sink saturation and non-permanence have significant implications for the cost efficiency of carbon sequestration. In the early phase of adoption, when the sequestration rate is high, the cost efficiency is also high. With lowered sequestration rates in later stages, the cost efficiency drops, making carbon sequestration continuously more expensive. Finally, if a new equilibrium is reached and no further sequestration takes place, costs would still apply. Reverting to previous practices would release carbon sequestered during the accumulation process.

This scenario of subsidised carbon sequestration, while adequate for measures making use of increased organic input, is not necessarily realistic in any case. It can be observed in North and South America, where conservation tillage has been adopted on a large scale (around 16% of the agricultural area in the US and 32% in Argentina), without being financially supported for climate change mitigation purposes. The main reasons for the adoption of conservation tillage lie in reduced expenditure of time, fuel and investment into heavy tractors. However, the conversion from conventional tillage to conservation tillage implies new machinery, and thus an initial investment into conversion may in some cases have led to a more cost efficient production method.

### 5.5 Availability of land and adoption of measures

When calculating totals, the area where it is feasible to carry out a specific measure should be taken into account. For example, application of farmyard manure is restricted by the amount of manure produced and environmental restrictions (such as ground water pollution), and conversion of arable land to grassland is restricted to the area of land not needed for arable production. Finding these data, which are not fully available, would be an important step forward in assessing regional differences in the efficacy of carbon dioxide abatement options in European agriculture.

Other factors limiting the implementation of soil carbon sequestration measures are the availability of suitable land / soils and the availability of limited resources (such as the amount of sewage sludge, animal manure or cereal straw available). An estimate of the potential attainable by the end of the first Kyoto Commitment Period (2012) is provided in Table 1, though more work needs to be done in estimating social and economic limitations to the implementation of these measures.

## 6 Monitoring and verification of carbon sequestration

Accurate monitoring and verification of carbon stocks and changes in soil carbon is essential if any measure is to be successfully implemented - otherwise we cannot account for the success (or failure) of different measures with sufficient level of certainty.

For the verification of activities under Article 3.4 of the Kyoto protocol, estimates of carbon fluxes and / or changes in carbon stocks are required that are independent of those used in the national report of a party to the protocol. This means that for a given human-induced activity, there must be at least two independent methods for assessing the size of an emission by a source or removal by a sink. Whether or not Article 3.4 is verifiable depends critically on what the parties to the protocol decide is acceptable in terms of verifiability. This report assumes an intermediate stringency in which national reporting will be based on either standardised values for carbon sequestration or regional factors for carbon sequestration derived from benchmark sites. Verification then means monitoring through additional independent measurements in conjunction with modelling, ground-based and airborne observations. However, in order to provide a reliable estimate of soil carbon and nitrogen stocks under different land use and management, the existing soil maps need further refinement.

A monitoring of soil conditions, including organic matter content, is advised to be supported by future EU legislation in the framework of the EU Soil Strategy. The Commission recognised in its Communication “Towards a Thematic Strategy for Soil Protection“ (COM (2002) 179 final) the need to address a soil protection policy and the need to develop a more complete information basis, monitoring and indicators to establish the prevailing soil conditions, and to evaluate the impact of diverse policies and practices. The proposal provides for a soil monitoring legislation, making use of existing information systems, databases and know-how, in so far as possible.

# 7 Impact of carbon sequestration measures on farm income and environmental side effects

Although it is very difficult to assess the impact of carbon sequestration measures on farm profitability and/or costs, it is possible to describe these effects qualitatively. Many carbon sequestration measures have positive as well as negative effects on farm profitability. For most measures it is impossible to define whether the overall impact on farm profitability would be positive or negative. Variation is expected between different farms, as well as for the industry as a whole in different Member States, for instance, due to different agri-environmental support schemes. For a few, a positive net benefit is expected, and these measures may be economically viable once they are introduced. However, initial costs of conversion and / or lack of information may be limiting factors for an adoption of new techniques.

For some measures it is possible to provide a rough estimate of potential net benefits. Within the rural development policy (agri-environmental scheme), a measure for no tillage in combination with a mulch-seed system exists e.g. in Germany, where between 25 and 60 € $ha^{-1}$ is paid for this measure. Within the ECCP, 20 € for the reduction of 1 t $CO_2$ is assumed to be cost effective. Taking this figure and an adsorption potential of 1.1 t $CO_2$ $ha^{-1}$, a payment of up to 22-€ $ha^{-1}$ could be considered cost effective in terms of carbon sequestration. The economic benefits from $CO_2$ sequestration, e.g. realised under an emission trading scheme, could finance additional agri-environmental measures. This may be worth even more if soil quality/function benefits are taken into account. However, with present market prices as low as 3 € per t $CO_2$ the economic benefit per hectare would be significantly reduced.

It must, however, be taken into account that the removal of $CO_2$ from the atmosphere by sinks is non-permanent. Thus, future costs may need to be taken into account to maintain elevated carbon stocks in the soil even if no further sequestration may occur. In comparison, investments into emission reductions rather than removals by sinks have a climate mitigation effect for several hundreds of years, which is the residence time of $CO_2$ in the atmosphere.

# 8 Synergies between climate change mitigation and soil protection

In addition to contributing to climate change mitigation, soil carbon plays a crucial role in soil protection. In its recent communication “Towards a Thematic Strategy for Soil Protection” (COM (2002) 179 final) the European Commission recognises that the decline in organic matter is among the major threats to soil that endanger its functions, together with erosion, local and diffuse contamination, sealing, compaction, a decline in bio-diversity and salinisation. Organic matter plays a central role in maintaining key soil functions and is an essential determinant of erosion resistance and soil fertility. It assures the binding and buffering capacity of soil, thus contributing to control diffuse pollution from soil to water.

# 9 Policy instruments supporting carbon sequestration

Within the first pillar of the Common Agricultural Policy, the Agenda 2000 reform introduced environmental protection requirements, whereby Member States should take the environmental measures they consider to be appropriate in view of the situation of the agricultural land used or the production concerned. These measures may include support in return for agri-environmental commitments, general mandatory environmental requirements or specific environmental requirements constituting condition for direct payments. Member States should decide on penalties for non-respect of environmental requirements, which may include a reduction or the cancellation of the market support.

The CAP already provides opportunities for measures aimed at carbon sequestration and soil protection. A number of agri-environmental measures offer opportunities for the build-up of soil carbon, the enhancement of soil biodiversity, the reduction of erosion, diffuse contamination and soil compaction. These measures include support to organic farming, conservation tillage, the protection and maintenance of terraces, safer pesticide use, integrated crop management, management of low-intensity pasture systems and lowering the stocking density and the use of certified compost. These measures can be developed further to enhance beneficial practices.

The CAP reform proposal (COM (2003) 23 final) constitutes an important step towards a greater contribution of agriculture to GHG mitigation. It provides for incentives for extensification and ensuring compliance with environmental legislation, which are expected to reduce nitrogen fertiliser use and thereby reduce $N_2O$ emissions. An aid of 45€/ha as a support for energy crops is proposed. In addition to that, increased soil carbon sequestration is likely to result from less intensive arable production, and in particular from increased organic farming, and from the fact that set-aside land is planned to be taken out of arable production. Set-aside will be non-rotational; however, member states will be able to allow rotational set-aside where this was necessary for environmental reasons. If non-rotational set-aside land will be ploughed rarely or not at all, carbon sequestration is expected to increase compared to the conditions on rotational set-aside.

The proposal provides for a transfer of funds from the first (market) pillar to the second (rural development) pillar of the CAP by means of modulation. The proposed additional funding for Rural Development Plans could lead to benefits for carbon sequestration, if Member States will invest it, in increased soil protection measures. Generally, more funds available for agri-environmental measures should stimulate an increased adoption of environmentally friendly production techniques.

The proposal includes that direct payments to farmers will be conditional to cross-compliance relevant to requirements to maintain land in good agricultural condition, among other aspects. Targeted measures aimed at soil protection, the conservation and enhancement of soil organic matter and soil structure, which are included in these requirements, are listed in Annex IV to the Proposal. Furthermore a new chapter entitled 'Meeting Standards' includes the possibility for Member States to offer temporary and degressive support to help their farmers to adapt to the introduction of demanding standards based on Community legislation concerning the environment, public, animal and plant health, animal welfare and occupational safety. Additionally, a farm advisory system is proposed to be mandatory as a part of cross-compliance requirements. Farm audits will involve structured and regular stocktaking and accounting of material flows and processes at enterprise level defined as relevant for a certain target issue (environment, food safety, and animal welfare). Support for farm audits will be available under rural development. As a result, farmers' awareness about potentially superfluous and environmentally negative input in agricultural production should be increased.

# 10 Conclusion

Some of the technical measures identified in this report appear to be suitable tools for the European agricultural sector to help combat global warming. These measures are to some extent already used in different Member States and are eligible for inclusion in national Rural Development Programmes, where they can be financially supported under the Agri-Environment Scheme. The CAP reform proposal provides for increased opportunities to support environmentally friendly agricultural production, including measures in favour of carbon sequestration.

The overall estimate of the carbon sequestration potential is limited by strong regional differences in (1) the sequestration potential of the measure, (2) the environmental impact of a measure, and (3) the socio-economic impact of the measure. This regional variation prevents a uniform strategy for carbon sequestration across the whole EU and makes a decentralised strategy, which takes into account the national, regional and even site-specific variation in socio-economic and environmental factors, more promising.

Generally, it has to be stressed that soil carbon plays an important role for the vital functions of soil and contributes to the long-term maintenance of soil fertility and function. Measures for carbon sequestration have therefore to be viewed not alone from the perspective of climate change mitigation, but also from the viewpoint of their contribution to a European policy of soil protection.

Carbon sequestration in soils is likely to have only a limited potential for greenhouse gas mitigation in isolation. It needs to be part of a broader strategy of measures for greenhouse gas mitigation and would provide added value to efforts to improve the sustainability of soils and agriculture through increased organic carbon levels in soils. The greatest potential of the measures discussed is likely to come from the substitution of fossil fuels with bio-energy crops, which has the double benefit of offsetting carbon emissions and additional carbon sequestration in soils.