European Climate Change Programme (ECCP)

Working Group Sinks Related to Agricultural Soils

Final Report

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Glossary

C	Carbon
CAP	Common Agricultural Policy
CH_4	Methane
CMO	Common Market Organisation
CO_2	Carbon dioxide
COP	Conference of the Parties of the UNFCCC
EAGGF	European Agricultural Guidance and Guarantee Fund
EC	European Community
ECCP	European Climate Change Programme
ESB	European Soil Bureau
GHG	Greenhouse gas
IPCC	Intergovernmental Panel on Climate Change
LFA	Less Favoured Areas
LU	Livestock unit
LULUCF	Land use, land use change and forestry
N	Nitrogen
N_2O	Nitrous oxide
NVZ	Nitrate Vulnerable Zone
RDP	Rural Development Plan
RES	Renewable Energy Sources
RMU	Removal unit (metric ton CO_2-equivalent)
SRES	IPCC Special Report on Emission Scenarios
UAA	Utilised agricultural area
UNFCCC	United Nations Framework Convention on Climate Change

Global warming potentials: CO_2=1, CH_4=21, N_2O=310 (IPCC 1996).

1 Summary

Carbon sequestration in agricultural soils has a potential to significantly contribute to climate change mitigation. There is a 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. Promising technical measures are linked to reduced soil disturbance and increased input of organic materials to arable fields. More specifically, the most efficient measures include (see also Table 1):

- the promotion of increased carbon input from organic amendments (animal manure, compost, crop residues, sewage sludge)
- organic farming
- conservation tillage
- permanent revegetation of set-aside areas with perennial grasses
- woody bioenergy crops instead of rotational fallow

A high potential for greenhouse gas mitigation is also seen in reduced CO_2 emissions from the reduced cultivation of organic soils, in particular due to the creation of a more shallow water table and the rewetting of grasslands on peat soils. These measures, however, imply a drastic change of current agricultural practices, and loss of income, which would have to be compensated by the Community.

A substantial spatial component in the net sequestration potential may be expected, however, because of regional differences in soil, site, and climatic conditions. Consequently, uncertainties in these estimates are >50 %. It is also unclear whether the new management will really be implemented by the farmer on a permanent basis. To support the development of climate policies, regional estimates of the carbon mitigation potential of land-management strategies are helpful. Such estimates should be supported by regional specific data on soil, climate, land cover, land management and ecosystem productivity. These data are, however, not readily available or too coarse for calculating accurate estimates and use is made of country data provided by the FAO. This resolution is, however, too coarse and produces an unbalanced picture. Creating data sets on above mentioned topics covering Europe at a high (sub-country) resolution will improve estimations and will allow selection of areas with high carbon sequestering potential.

Monitoring and verification of policy measures under the Kyoto Protocol has some further complications. Stringent verification is a painstaking, labour-intensive exercise. If the parties decide on a stringent level of verifiability, Article 3.4 is at present, and is likely to remain in the future, unverifiable (Royal Society, 2001). If less stringent levels of verifiability are adopted, a low level of verifiability might be achieved by most parties by the beginning of the first commitment period. The

information needed for adequate monitoring and verification in addition to the available one depends on the political decision what level of stringency is required. Some of the required information will need to be derived from models.

The direct effect of existing CAP measures on carbon sequestration in agricultural sinks cannot always be quantified due to interactions with other socio-economic drivers. Indirectly, however, some production-related policies and the agri-environmental schemes have helped to maintain carbon stocks in agricultural soils. Specific effects include the increase in carbon stocks through afforestation subsidies, the encouragement of organic farming, and the introduction of set-aside with its scope for biofuel production with perennial species. Conversely, however, LFA schemes may have contributed to the maintenance of lower than natural carbon stocks in extensive grazing areas, which might otherwise have been abandoned and revegetated by species that assist carbon sequestration.

The CAP reform proposal (COM (2003) 23 final) constitutes an important step towards a greater contribution of agriculture to GHG mitigation. 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, thus providing incentives for extensification and an increased adoption of sustainable and environmentally friendly production techniques. 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. The proposal includes that direct payments to farmers will be conditional to cross-compliance with environmental legislation, which are expected to reduce nitrogen fertiliser use and thereby reduce N_2O emissions, and with requirements to maintain land in good agricultural condition. These include targeted measures aiming at soil protection, the conservation and enhancement of soil organic matter and soil structure. 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. Additionally, an aid of 45€/ha as a support for energy crops is proposed.

Finally, it should be noted that the EU has now embarked on a thematic approach to soil protection within the context of the 6th Environmental Action Plan. While this strategy will encompass all aspects of soil protection for sustainable use, the Communication launching the path towards the strategy already has indicated concern about the decline in organic matter in European soils and the need for action to address this.

Table 1 Most promising technical measures

	Technical measure	Seques-tration Potential per unit area [t CO_2 ha^{-1} y^{-1}]	Potential in EU-15 during first commit-ment 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 extensive permanent pasture) or extensivation of arable production by introduction of perennial components	2-7	15	Benefits for wildlife, biodiversity, amenity provided revegetation goes beyond Good Farming Practice	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.

[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.

					However, lower yields per ha, compared to conventional farming.
5	Promote permanently shallow water table in farmed peatland	5-15	15	Benefits for wildlife, biodiversity, amenity, water retention, reduced N_2O	Regionally specific, positive only if linked to compensation payment for nature protection. Some peatlands 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.

2 Introduction

2.1 Objectives of the ECCP Working Group Sinks Related to Agricultural Soils

The objective of the Working Group Sinks Related to Agricultural Soils is to provide the scientific background for the following issues:

1. Clarifying the uncertainties connected with the measures already discussed in the ECCP Working Group Agriculture, as well as completing these measures, where appropriate. The possible implementation of the measures should be in accordance with the criteria described under Article 3.4 of the Kyoto Protocol.
2. Providing for all selected measures, a quantitative estimation of the carbon absorption potential per hectare and the surface of agricultural land that is available and suitable for the implementation of those measures.
3. Looking at carbon stored in farm soils, the working group should analyse the organic matter issue and the broader aspects of soil protection linked to it.
4. Possibilities of alternative use of peatlands and its long-term effects, as well as the environmental and social side-effects, should be considered.

5. The issue of composting and use of sewage sludge in agriculture should be considered as possible means of building up soil organic matter.

6. Reporting on the implementation and the monitoring of LULUCF (land use, land use change and forestry) activities is an important factor influencing whether carbon absorption by soils can be accounted as a sink under Article 3.4 or not. Even if the detailed reporting requirements will be decided on the basis of the IPCC recommendations on good practice, the working group should make the link to how far the monitoring of different measures is possible and reasonable from an economic point of view. In doing so, it will need to be aware of the great variation in organic matter between different soils due to parent materials, climatic conditions, other geographical aspects and agricultural activities.

7. The extent to which the existing instruments of the CAP are already contributing to an increase or decrease of the carbon sequestration potential of agricultural soils should be considered. In this respect, relevant CAP instruments to be examined could be, for instance , agri-environmental schemes covered by the Rural Development Regulation (EC) No 1257/1999, environmental protection requirements established under Article 3 of Regulation (EC) 1259/99, as well as sectoral policies (e.g. arable crops, olive oil).

8. Furthermore, the effects on farm income and environmental side-impacts of different possible policy options, which seem to be relevant regarding the implementation of the Kyoto Protocol (Article 3.4), should be considered.

2.2 Accounting for Agricultural Carbon Sinks under the Kyoto Protocol

Carbon sequestration in agricultural soils is accountable under Article 3.4 of the Kyoto Protocol (additional human-induced activities related to changes in greenhouse gas emissions by sources and removals by sinks in the 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. For activities under Article 3 paragraphs 3 and 4 the following definitions and rules apply (FCCC/2001/13).

- Definitions:

- "Cropland management" is the system of practices on land on which agricultural crops are grown and on land that is set aside or temporarily not being used for crop production;
- "Grazing land management" is the system of practices on land used for livestock production aimed at manipulating the amount and type of vegetation and livestock produced;
- "Revegetation" is a direct human-induced activity to increase carbon stocks on sites through the establishment of vegetation that covers a minimum area of 0.05 hectares and does not meet the definitions of afforestation and reforestation.

- Reporting requirements (Article 3.7, 3.8, and 5) with regard to a national system for the estimation of anthropogenic emissions and removals of greenhouse gases and annual inventories for all years from 1990.
- Modalities for accounting of assigned amount units under Article 7.4: Identification of a country's election of activities under Article 3.4, for inclusion in its accounting for the first commitment period, together with information on how its national system (Article 5.1) will identify land areas associated with the activities and identification of whether, for each activity under Article 3.3 and 3.4, it intends to account annually or for the entire commitment period.
- Application of IPCC Guidelines: IPCC Guidelines for reporting and accounting for greenhouse gas emissions and removals by LULUCF have not been adequately completed. During 2002/2003, IPCC will elaborate methods to estimate, measure, monitor, and report changes in carbon stocks and anthropogenic greenhouse gas emissions and removals resulting from LULUCF activities under Article 3.4 and others. IPCC will also elaborate the respective guidelines for good practice guidance, develop definitions and methodologies for accounting for activities of degradation of forests and revegetation.

Carbon sinks by LULUCF are accounted as removal units ("RMU"). One RMU is equal to one metric ton of CO_2-equivalent.

2.3 Carbon Sequestration and Soil Protection

Over the centuries, soil organic matter has come to be considered as the *elixir of plant life*. At a very early stage in history, man discovered that soil colour is closely correlated with organic matter that derives mainly from decaying plant materials. Soils high in organic matter were also found to be productive, both for crop production and for providing good pasture for grazing animals. To ensure sustainable management of the land, therefore, it is imperative that organic matter in the soil is maintained and sustained at satisfactory levels. A decrease in organic matter content is an indicator of a lowered quality in most soils. This is because soil organic matter is extremely important in all soil processes.

Soil organic matter is composed of organic material (plant root remains, leaves, excrements), living organisms (bacteria, fungi, earthworms and other soil fauna) and humus, the stable end product of the decomposition of organic material in the soil by the slow action of soil organisms. As such it is constantly built up and decomposed, so that the soil organic carbon contained in the organic matter is released to the atmosphere as CO_2 and recaptured through the process of photosynthesis.

The benefits of soil organic matter are linked closely with the fact that it acts as a storehouse for nutrients, it is a source of fertility, and it contributes to soil aeration thereby reducing soil compaction. Organic matter is also an important ‘building block’ for the soil structure and for the formation of stable aggregates (Waters and Oades, 1991, Beare *et al.*, 1994). Other benefits are related to the improvement of infiltration rates and the increase in storage capacity for water. Organic matter also serves as a buffer against rapid changes in soil reaction (pH) and it acts as an energy source for soil microorganisms.

Soil organic carbon is a major component of the organic fraction in soil. It positively affects a number of physical, chemical and biological soil properties and, consequently, soil functions. An increase of soil organic carbon enhances aggregate stability for better erosion control and enhances cation exchange capacity and the buffering capacity for nutrients and pollutants through variable surface charges of the humic substances. Soil biological activity favours soil fertility, resilience and often pest control. Macrofauna enhances soil aeration and infiltration capacity by the creation of continuous macropores connecting the topsoil with the subsoil. In summary, soil organic carbon maintains important soil functions with regard to habitat, biological diversity, soil fertility, crop production potential, erosion control, water retention, matter exchange between soil, atmosphere, and groundwater, and the filtering, buffering and transforming capacity (Huber et al., 2001; Kirchmann and Andersson, 2001).

Land management affects carbon sequestration or loss rates as well as the release of other greenhouse gases from soils, which are in turn also affected by climate change. Soil organic carbon turnover is a function of the input of residues and other organic matter as opposed by decomposition rates, which are, in turn, modified by soil management, and interactions with site conditions, climate and vegetation. Intensive arable farming has depleted the soil organic carbon stocks over the last decades and has favoured topsoil and subsoil compaction through heavy traffic. Intensive tillage to loosen the soil again further depletes organic carbon contents, further weakens soil structure and will, especially in poorly structured sandy and silty soils, produce a cycle of new compaction, loosening etc. Conservation tillage has therefore been promoted since the 1960s in order to avoid soil losses through erosion, eutrophication of surface waters and save labour requirements. The success of non-turning soil management systems, however, relies strongly on site-specific characteristics, the farmers´ awareness and knowledge and often on higher and more frequent application of herbicides. Increasing litter input by organic fertilisers, green manuring and cover crops increases both soil organic carbon contents and crop yields.

Maintaining adequate soil organic carbon contents in agricultural soils is being used as one of the key indicators for soil quality and sustainable agricultural land use in Sweden (Kirchmann and Andersson 2001) and suggested for Europe (Huber et al. 2001). Carbon sequestration in agricultural soils hence produces a range of ancillary environmental, social and economic benefits.

3 Potential Measures and Quantitative Estimation of Carbon Absorption Potential in Agricultural Soils

3.1 Potential measures for carbon sequestration in agricultural soils

3.1.1 Options for sequestering carbon in mineral soils

In agriculture, the larger part of the carbon is stored in the soil. Increasing the soil carbon content can be done by increasing the carbon input, decreasing the output or a combination of the two. Input is mainly determined by the net primary production. Loss of carbon is determined by decomposition and loss of topsoil via erosion. The rate of decomposition is controlled by ambient temperature and soil physical and soil chemical conditions.

Evaluation of current and possible new management practices for carbon sequestration will therefore focus on the input and the output of soil organic carbon. Possible changes of emissions of N_2O and CH_4 are important when determining the mitigation effect of a given activity.

Kyoto Article 3.4 activities relating to soil carbon sequestration are often grouped under the following headings, cropland management, grassland management, forest management and revegetation (IPCC: Watson et al., 2000). The measures considered by the IPCC in the Special Report on LULUCF (as summarised in Smith, 2001) were cropland management to provide higher carbon inputs to the soil, irrigation water management, conservation tillage, erosion-control practices, management of rice cultivation, grazing management, protected grassland / set-aside, grassland productivity improvements, fire management in grasslands, agro-forestry at the margins of the humid tropics, replenishment of soil fertility through agro-forestry in sub-humid tropical Africa, forest regeneration, forest fertilisation, forest fire management, pest management, forest harvest quantity and timing, low-impact forest harvesting, restoration of former wetlands, and restoration of severely degraded land.

This report is concerned with agricultural soils, so forest management and revegetation (except on set-aside land) will not be considered further here, and neither will carbon sequestration in wetlands, urban forests, deserts, sediments, tundra or taiga. This report concentrates upon cropland and grassland management, though organic soils are also considered where they are used for agriculture. As well as management changes within a single land-use (e.g. reduced tillage on cropland), transitions between land-uses are also considered (cropland to grassland conversion).

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. Soil carbon loss can also be slowed through improved management.

Measures for reducing soil disturbance include:

- 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.
- Reduced tillage, in which 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 potential environmental and socio-economic impacts can thus only be estimated qualitatively, in comparison to zero tillage or in comparison to standard tillage practices.
- Set-aside land;
- Growth of perennial crops.

Measures for increasing soil carbon inputs include the better use of:

- Animal manure, sewage sludge or compost, by applying all available material on cropland instead of grassland. This requires some transport of material from regions of intensive manure production to suitable croplands.
- Crop residues;
- Improved rotations with higher carbon inputs to the soil;
- Fertilisation and Irrigation to increase productivity;
- Livestock management, including changes in the number of animals grazing on the land, the stocking rate and time the animals spend on a particular area of land;
- Changes in cutting method and frequency of grass land, such as an increased cutting for hay instead of the production of silage, and different lengths of cut.

Switching from conventional arable agriculture to other land-uses with higher carbon inputs or reduced disturbance will also increase soil carbon stocks, e.g.:

- Bioenergy crop production (restricted to perennial herbaceous and woody species only);

- Conversion of arable land to grassland. This option includes the possibility to expand field margins to 20 m, on which grass should be grown, and possibly shrubs or trees.
- Conversion of arable land to woodland (afforestation);
- Natural regeneration;
- Extensification, which means to extend the crop rotations and include more intercrops and grasses in order to increase the carbon input to soil;
- Organic farming and integrated farm management. Both agricultural cultivation systems include a number of different measures, which potentially contribute to carbon sequestration, such as the substitution of mineral nitrogen fertiliser by animal manure and the use of green manure as well as cover crops. It must be noted that the actual sequestration rate that is achieved under these cultivation systems depends on the extent to which these measures are used. Integrated farm management is not considered further in this report but may reach similar sequestration rates if making use of these techniques.

The potential for carbon sequestration of these measures is discussed in section 2.2.

3.1.2 Alternative use of peatlands

Virgin peatlands take up carbon at rates between 0.4 and 1.2 t ha^{-1} y^{-1} CO_2, but emit CH_4 at significant rates, turning them into a source of 0.5 to 5.6 t ha^{-1} y^{-1} CO_2-equivalents (Cannell and Milne 1995; Figure 1). The cultivation of peatlands leads to a release of carbon from rapid peat oxidation, which is as strong as 8 to 20 t ha^{-1} y^{-1} CO_2 under land use systems with deep drainage and intensive mechanical soil disturbance, especially after deep ploughing. Whilst CH_4 emissions more or less cease completely after drainage, N_2O emerges at rates that exceed those from mineral agricultural soils by a factor of 2 to 10. In total, greenhouse gas emissions from agricultural peat soils exceed those from virgin peatlands by a factor of 2 to 6 (Figure 1). Estimation of the annual carbon dioxide emissions from drained lowland peats in the Netherlands range from 0.4 to 27.0 t CO_2 ha^{-1} y^{-1}. This is mainly because of differences in methods and environment (Kuikman et al., 2002).

Drainage depth is the most important factor in CO_2 emissions from peat soils, as oxidation is an aerobic process. Decomposition rates are also controlled by precipitation, air temperature and peat type. Decomposition rates in eutrophic peats are 2 to 3 times higher than oligotrophic peats (Hendriks, 1993). The presence of a mineral (clay) layer reduces the decomposition of peat (Schothorst, 1979). In the context of carbon sequestration, the rationale for alternative use of peatlands is the preservation of the existing large carbon stocks in peat soils and the reduction of anthropogenic greenhouse gas emissions rather than an increase of soil carbon stocks in the short term.

Potential alternative uses of agricultural peat soils include the avoidance of row crops and tubers, avoidance of deep ploughing, maintenance of a more shallow water table and the conversion of arable cropping to permanent cultures as well as new crops on restored wetlands.

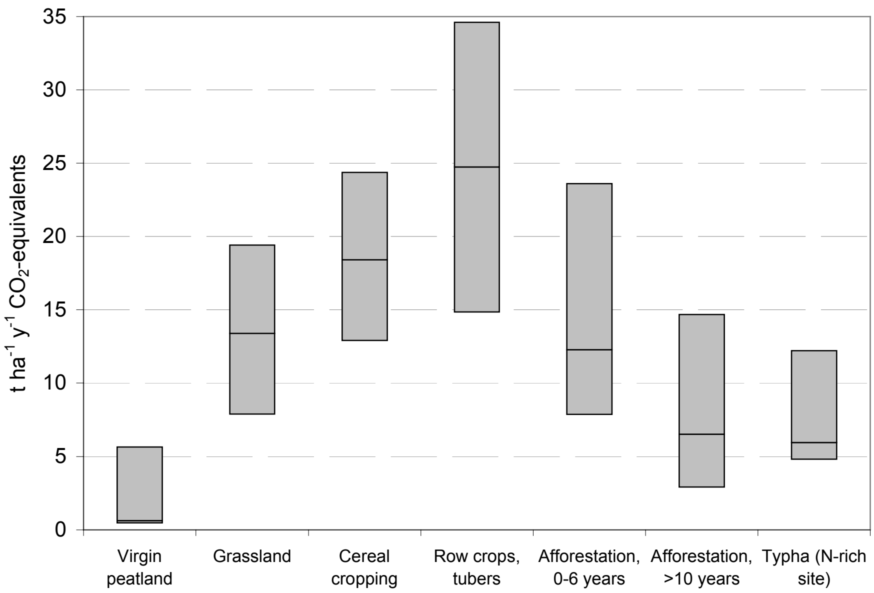


Figure 1 *Greenhouse gas emissions from peatlands. Virgin peatland: average for Northern regions (cited in Cannell and Milne 1995); grassland, cereal cropping, row crops and tubers: average for European peat soils (Freibauer in press); afforestation: sites in Ireland, Scotland and Finland (Byrne and Farrell 2001; Cannell et al., 2001; Maljanen et al., 2001);* Typha: *German constructed wetland (Kamp et al., 2001).*

3.2 Potential of different agricultural management options for sequestering carbon in soils

Lal et al. (1998) provided estimates of the carbon sequestration potential of agricultural management options in the USA. Few studies have estimated agricultural soil carbon sequestration potentials for Europe. Early estimates by Smith et al. (1997, 1998a, b) were reviewed and other estimates added by Batjes (1996) and Nabuurs et al. (1999). The most recent estimates were made by Smith et al. (2000) and Vleeshouwers & Verhagen (2002); estimates based on values in these papers are presented in Table 2 along with rough estimates of uncertainty associated with these figures.

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 harvest index (Evans, 1993). So while grain yields increased, the amount of crop residues was even reduced.

A simple calculation shows the high theoretical potential that lies in carbon sequestration in agricultural soils: In theory the overall yearly CO_2 emissions from a whole nation of Italy (541.5 Mt CO_2 being emitted yearly, roughly 30 million hectares total land area) could be offset by a sequestration of just 0.14% organic carbon in soils (ECCP, 2001).

Table 2 Measures for increasing soil carbon stocks in agricultural soils and potential yearly soil carbon sequestration rates (t CO_2 ha^{-1} y^{-1}).

Measure	**Potential soil carbon sequestration rate (t CO_2 ha^{-1} y^{-1})**	**Estimated uncertainty (%)**	**Reference / notes**
Crop-land			
Zero-tillage	1.42 but see reference	> 50%	1, 2
Reduced-tillage	< 1.42	>> 50%	3
Set-aside	< 1.42	>>50%	4
Perennial grasses and permanent crops	2.27	>50%	5
Deep-rooting crops	2.27	>50%	5
Animal manure	1.38	> 50%	1
Crop residues	2.54	> 50%	1
Sewage sludge	0.95	>50%	1, 15
Composting	1.38 or higher	>>50%	6, 15
Improved rotations	>0	Very high	7
Fertilisation	0	Very high	8
Irrigation	0	Very high	8
Bioenergy crops	2.27	>>50%	1
Extensification	1.98	>>50%	1
Organic farming	0-1.98	>>50%	9
Convert arable to woodland	2.27	>>50%	1
Convert arable to grassland	7.03 ± 2.08	110% (2.3 to 11.2)	10
Convert grassland to arable	-3.66	>>50%	11
Convert permanent crops to arable	-3.66	>>50%	11
Convert woodland to arable	-?	?	?
Grassland			
Increase in the duration of grass leys	0.4-1.8	?	14
Change from short duration to permanent grasslands	1.1-1.5	?	14
Increase of fertiliser on nutrient poor permanent grassland	0.7	?	14
Intensification of organic soils with permanent grassland	-3.3-4.0	?	14
Livestock management	??	??	?
Cutting method and frequency	?	?	?
Fire protection	??	-	?
Revegetation			
Abandoned arable land	2.27	>>50%	12
Farmed organic soils			
Protection and restoration	Up to 17	Range 0–17. Spatial	13

		variability high	
Avoid row crops and tubers	0	>50%	13
Avoid deep ploughing	5	>50%	13
More shallow water table	5-15	>50%	13
Convert arable to grassland	5	>50%	13
Convert arable to woodland	2-5	>>50%	13
New crops on restored wetlands from arable	8-17	>50%	13
New crops on restored wetlands from grassland	3-12	>50%	13
Sheep grazing on undrained peatland	>8	>50%	13
Abandon for conservation	>8	>50%	13

References / notes:

1. Smith et al. (2000); per hectare values calculated using the average C content of arable top soils (to 30cm) of 53 t C ha^{-1}; Vleeshouwers and Verhagen (2002), cf. Table 5. According to some experts, C accumulation resulting from no-tillage is over-estimated in the literature, some figures given by case studies appear not reliable – thus strong sequestration doubtful.
2. Uncertainty estimated from 95% confidence interval about the mean – statistical uncertainty of the mean only; actual uncertainty is higher.
3. Estimated from papers reviewed in Smith et al. (2000)
4. Assumed to be the same as zero tillage figure of Smith et al. (2000)
5. Assumed to be the same as for bioenergy crops figure of Smith et al. (2000)
6. Assumed to be the same as animal manure figure of Smith et al. (2000).
7. Minimal impact of arable rotations in papers reviewed in Smith et al. (2000) but perennial crops in rotations may increase soil carbon levels
8. Net carbon impact of irrigation and fertilisation is minimal or negative when carbon costs of producing fertiliser and pumping irrigation water are considered (Schlesinger, 1999)
9. Organic farming is increasing in Europe, but is not a single management practice. Within an organic farm, a combination of practices may be used including extensification, improved rotations, residue incorporation and manure use. These will contribute to carbon sequestration positively, but in different proportions depending of the degree of implementation of a given practice. Zero and reduced tillage are generally incompatible with organic farming since increased tillage is frequently used to control weeds. It is, therefore, impossible to assign an exact figure for the carbon sequestration potential of organic farming, but a range between the lowest and highest potential sequestration rate can be given.
10. From Vleeshouwers & Verhagen (2002). Also based on figures from Rothamsted grass to arable conversions; cf. Table 5.
11. From figures of Jenkinson (1988) used by Smith et al. (1996)
12. Per hectare value assumed to be the same as Rothamsted Geescroft natural regeneration (Poulton, 1996)
13. From Freibauer (in press). Carbon sequestration is from avoiding carbon loss from peats. Further benefit through reduced emission of N_2O, which is not compensated by increased CH_4 emissions.
14. Average net annual fluxes over a 20-yr. period (Loiseau, in: Arrouays et al., 2002).
15. The sequestration values are based on a loading rate of 1 t ha^{-1} y^{-1}, which was the lowest safe limit in place (in Sweden) at the time of analysis for this figure (1997). A higher loading rate would give a higher sequestration rate per area. As the limiting factor for the application of compost is the amount of producible compost, a higher loading rate on a certain area would imply that a more limited area could be treated.

3.3 Spatial variability of soil types and carbon sequestration

The figures given in Table 2 were largely derived using statistical relationships that averaged across soil types and climates. The per hectare carbon sequestration values were also derived for average European arable soils. As such, there is much variability among climatic regions and soil types in Europe (see European Soil Map, King et al., 1995; Heineke et al., 1998). 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 (Christensen, 1996). 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. The spatially explicit approach of Vleeshouwers & Verhagen (2002) has revealed regional differences in carbon sequestration potential (Table 5, Figure 2).

All land use options for arable land evaluated in this report reduce atmospheric CO_2 concentrations compared to business as usual, but only the application of farm-yard manure (and other organic fertilisers such as composted materials) and the conversion into grassland may turn arable land into net carbon sinks. The highest sequestration rates through the application of farmyard manure were calculated for South-West and South-East Europe (e.g. Spain and Turkey), where low soil carbon contents occur together with a dry summer season, which reduces the decomposition of soil organic matter. However, there are only small farmyard manure resources available in these regions. Conversion of arable land into grassland and leaving behind cereal straw exerted the greatest effect in West Europe, where grassland and cereal yields are highest. The effect of reduced tillage was highest where relatively high soil carbon contents occur simultaneously with relatively high decomposition rates, which occurs for example in the Netherlands and in North-Germany. The effect of a temperature increase interacts with the distribution of rainfall over the year. In countries where soil moisture allows decomposition all year long (e.g. in North-West Europe) increased temperature has the greatest effect on decomposition rates, and thus on the efficiency of reduced tillage.

The analysis of the 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. Different soils have different capabilities to sequester carbon. The potential for sequestration is higher in soils with low organic carbon content and decreases in soils with higher organic carbon content. The potential sequestration given in table 2 is an average (median) value. Being a first estimate, it makes no attempt to give an idea of spatial variability.

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 good or bad results according to the type of soil (i.e. mainly due to the texture, permeability, groundwater table level etc.). It is thus not possible to give an overall evaluation for a single action or treatment without taking into account the soil.

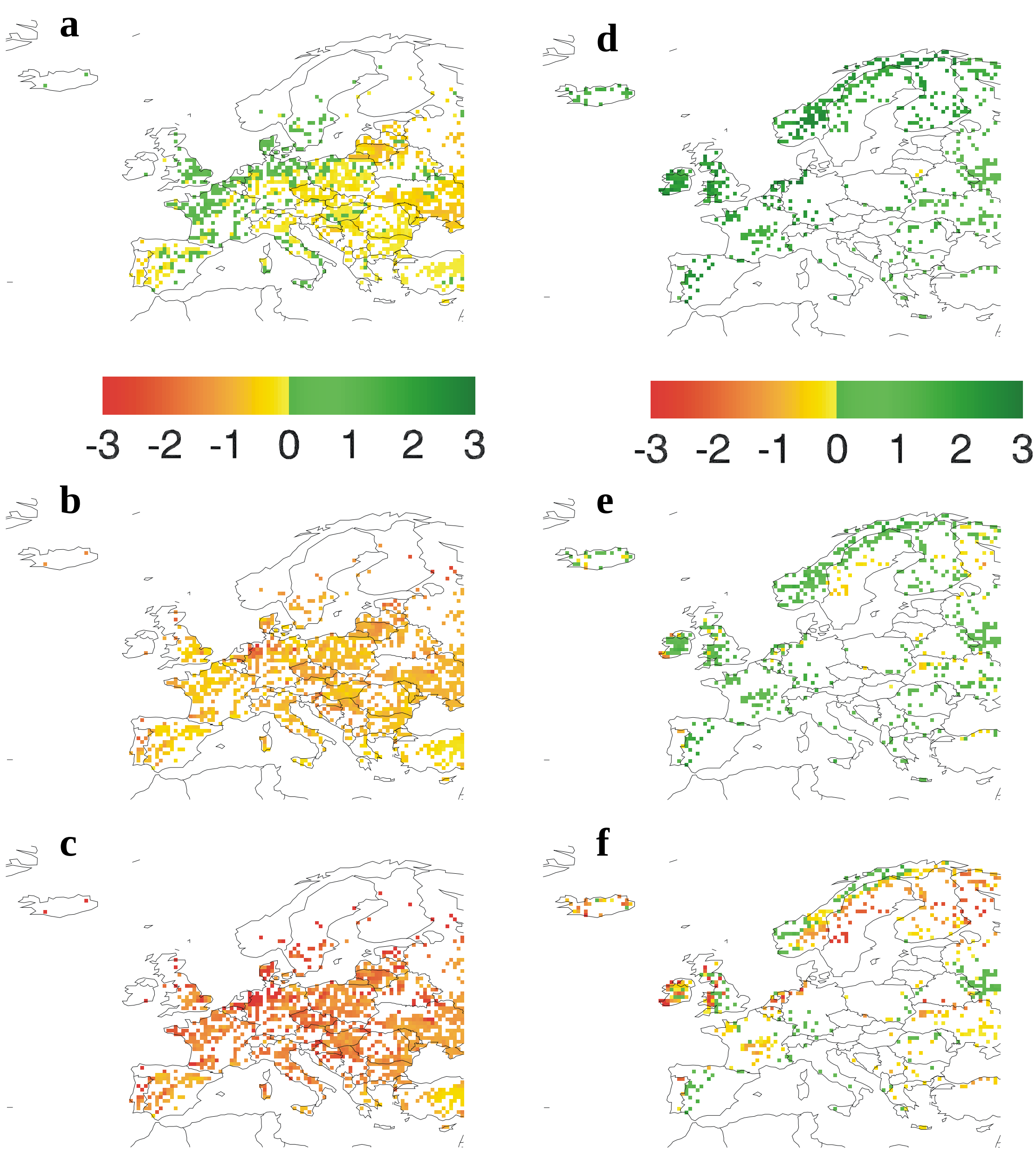


Figure 2 *Simulated carbon fluxes in soil organic matter in Europe (tC ha-1 y-1) in the commitment period 2008-2012 (business-as-usual scenario); (a – c) arable fields, (d – f) grassland. Simulations were made using the mean soil organic carbon content reported by as the initial situation in 2000 (b and e), mean organic carbon content minus standard deviation (a and d), and mean organic carbon content plus standard deviation (c and f).*

As a preliminary example to demonstrate the methodology that could be applied to study the actions and results on soils in terms of Carbon sequestration, the suitability of soils to the spread of sewage sludge is shown on a European map in Figure 3.

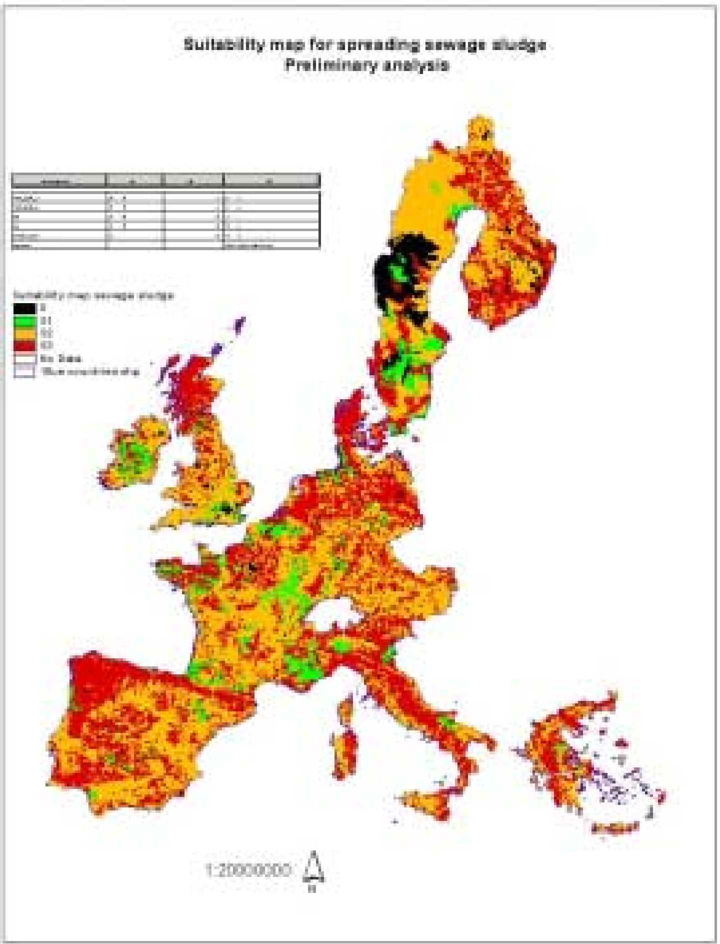


Figure 3: Suitability map for spreading sewage sludge. Using the European Soil Database at scale 1:1,000,000 (Vers.4.0) as a starting point, a suitability map for spreading sewage sludge in Europe was constructed (Rusco, ESB, Pers. Comm.2002). The main factors taken into account were: dominant surface texture, dominant subsurface texture, soil water regime, presence of impermeable layer in the soils. Suitability was assessed according to the FAO methodology in which land is identified as suitable, moderately suitable, or not suitable for the spreading of sewage sludge. These preliminary results need to be evaluated and verified, and the methodology does not include heavy metal data. In principle, better results could be obtained from using the SPADE (Soil Profile Analytical Database of Europe) data (Madsen and Jones, 1994). In SPADE, the data can be directly linked to different kinds of soils – Soil Typological Units (STUs) – and not just to the Soil Mapping Unit (SMU). The main aim of this elaboration is to establish the underlying benefit of each action proposed for increasing organic carbon in soils. As emphasised above the proposed actions should be strictly linked and evaluated according to soil type.

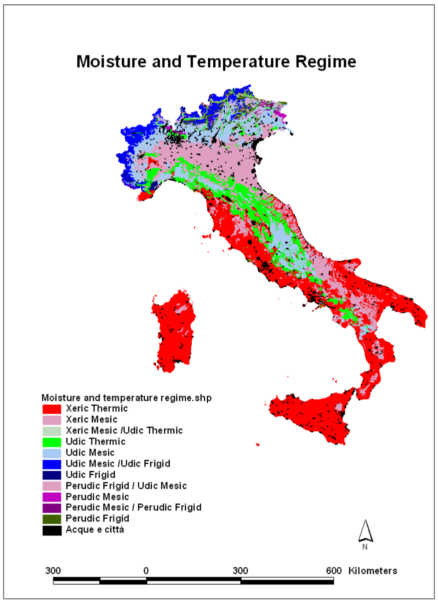
Regional differences are also expected concerning the applicability of compost. Any upscaling from local experiences to regional, national or even European estimates of the sequestration potential needs to take this variability into account.

In certain Italian Regions the application of organic fertilisers and composted products is currently supported under their regional Rural Development Plans (2000-06). This option is considered appropriate for these regions, where soil organic matter levels are low and a significant increase in soil organic matter could be achieved by an increased organic input.

The U.K. Department for Environment, Food & Rural Affairs (DEFRA), however, concluded that it would not be able to subsidise this measure under the England Rural Development Programme, stressing that composted material could not be applied to unlimited areas of agricultural land. DEFRA assumes the area available for this measure to be limited, particularly in northern member states, and questions the long-term potential to sequester carbon and continued year-on-year gains when compost and sewage sludge is applied to arable land.

However, some field trials demonstrate that also in Northern Countries the adoption of organic fertilisers may lead to an increase, or to slowing the decrease, of carbon in the soil, and so may be considered as an appropriate measure, albeit subject to variability of results under different climatic and farming conditions.

The approach used for a definition of a Potential Carbon Sequestration Index is another example of the important role soils play in the carbon sequestration process. In a pilot study in Italy, the European Soil Bureau has estimated the Potential Carbon Sequestration Index according to the parameters that influence carbon sequestration processes. Obviously, in this study, soil plays a fundamental role. The index shows the "potential" carbon sequestration, without consideration of the land use. To have a "real" carbon sequestration index it is necessary to evaluate also the influence of land use. The following figures show the results of this study. Obviously this approach needs to be combined also with other factors like socio-economic and environmental aspects.



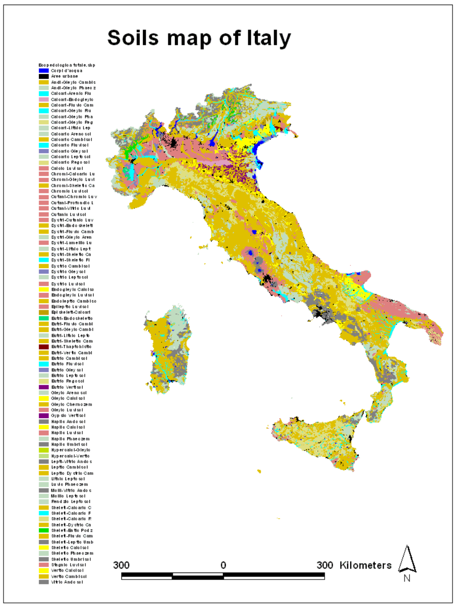


Figure 4 *Maps of Italy showing (left) the moisture and temperature regime and (right) the soil types. [Derived from the Ecopedological Map of Italy, Ministero dell'Ambiente, Italiano, 2001]*

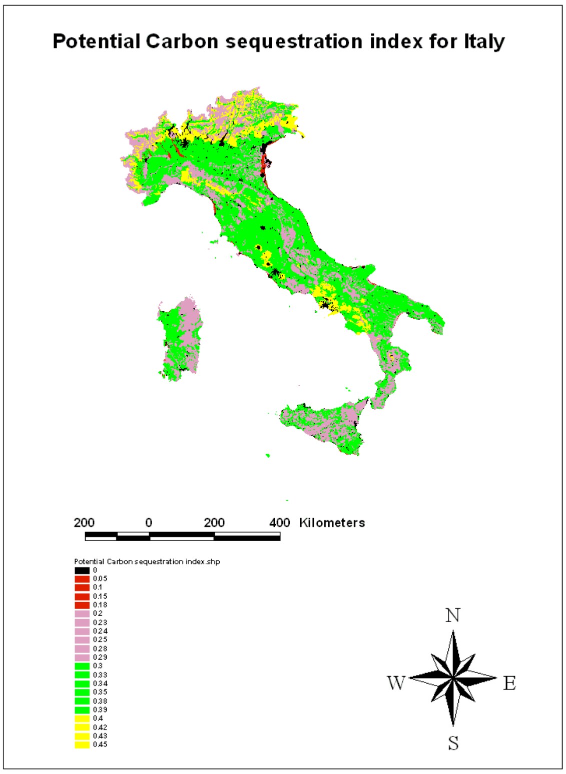


Figure 5: Potential carbon sequestration index for Italy (Rusco, ESB, Pers. Comm. 2002).

According to a recent study (Jones et al., 2001, 2003), more than a third of the soils in Europe are highly susceptible to compaction in the subsurface layers or horizons. Compaction of surface soil can, at least temporarily, be alleviated by mechanical loosening but in the subsurface horizons this is often difficult and expensive. Therefore any management system that is likely to increase subsoil compaction is not truly sustainable.

There is evidence that soil bulk density increases under zero and minimum tillage systems though the exact effects will depend on the cropping system, the type of machinery employed, the soil type, the soil conditions during the period when the fieldwork is done and a number of other factors. Although reduced tillage results in higher bulk densities, in most cases no reduction or even an improvement of soil qualities will occur, compared to conventional tillage. A prerequisite is that the fieldwork is done during the right conditions and the soil is not overloaded by too high wheel loads. If these conditions are fulfilled, then usually, subsoil compaction is reduced compared to conventional tillage, as undisturbed topsoil is stronger than a tilled soil and therefore will protect the subsoil. However, as evident from extensive research in Sweden and other European countries, there are also cases, in which reduced tillage may cause a poorer soil structure, resulting in a reduced rootability and infiltration due to the higher bulk density.

It should be noted that conventional tillage can as well result in soil compaction under certain conditions. The negative consequences of soil compaction, such as increased water runoff, are beginning to be seen as a serious problem. There is a clear need for more research and data on the causes of compaction under different farming systems and the effects for carbon sequestration as well as environmental implications.

Furthermore, even if the structure of already compacted soils may improve under zero or minimum tillage, recuperation of compacted soil is a slow process and the effectivity of the recuperation process decreases strongly with depth and may not sufficiently compensate compaction by heavy wheel loads. Thus, zero tillage, in the same way as conventional tillage, must be accompanied with an adequate protection of the soil by taking care that wheel loads do not exceed the strength of the soil.

It is therefore evident that soil conditions that, amongst others, may favour soil compaction have to be taken into account when considering measures for carbon sequestration. The detrimental effects of compaction go far beyond agricultural concerns of restricted root penetration, decreasing yields and increasing management costs. The overall deterioration in soil structure that may result from compaction, aggravated at times by a build up of water above the compacted layer can also:

1. increase lateral seepage of excess water over and through the soil, accelerating the potential pollution of surface waters by organic wastes (slurry and sludge), pesticides, herbicides and other applied agrochemicals;
2. decrease the volume of the soil system available to act as a buffer and a filter for pollutants;
3. increase the risk of soil erosion and associated phosphorus losses on sloping land through the concentration of excess water above compacted layers;
4. accelerate effective runoff from and within catchments.
5. increase greenhouse gas production and nitrogen losses through denitrification under wetter conditions.

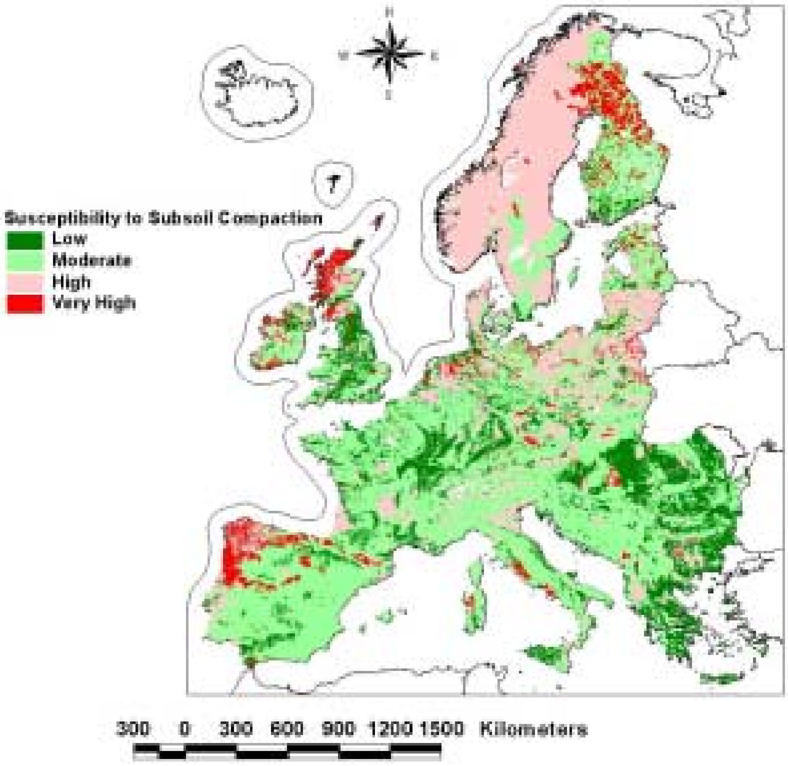


Figure 6: Susceptibility of soil compaction map of Europe.

Such studies highlight the importance of careful consideration of the impact of changes in agricultural practice. Minimum tillage may improve carbon stocks but if severe compaction occurs as a result then the overall effect may be negative. Further investigations are needed to improve spatial resolution of such interpretations to provide a more accurate basis for policy implementation.

As apparent from the spatial analyses above (Figures 3, 5 & 6) a major effort should be expended in future to have a better correlation between soil types and the actions to be taken in relation to carbon sequestration.

When calculating totals, the area where it is feasible to carry out a specific measure should be taken into account (Smith et al., 2000). For example, application of farmyard manure is restricted by the amount of manure produced, and conversion of arable land to grassland is restricted to the area of surplus arable land. Finding these data will be an important step forward in assessing regional differentiation in the efficacy of carbon dioxide abatement options in European agriculture. European totals based on estimates of the average gain of measures and the average proportion of agricultural areas that may be subjected to the measures were calculated by Smith et al. (2000a).

The relative effects of the different measures in the study by Vleeshouwers and Verhagen (2002) agree well with Smith et al. (2000, 2001) and long-term experiments referred to therein. Only the effect of applying farm-yard manure calculated by Vleeshouwers and Verhagen (2002) as 1.5 t C ha^{-1} y^{-1} clearly exceeds the one calculated by Smith et al. (2000, 2001) as 0.4 t C ha^{-1} y^{-1} although both studies apply farm-yard manure at 10 t fresh matter per hectare and use similar humification rates. However, the CESAR model tends to overestimate carbon sequestration rates when the supply of organic matter strongly increases (Vleeshouwers and Verhagen, 2002). Both studies rely on the assumption that farmyard manure spread on cropland sequesters more carbon than if spread on grassland, which has recently produced some controversy (Arrouays et al., 2002).

Farmyard manure, which partly consists of straw, is likely to be more resistant to decomposition than pure animal manure/slurry, which is the major waste product of more intensive pig, poultry and cattle production systems. Similar evaluations on the higher efficiency in promoting build-up of carbon in the soil should hold valid for composted organic fertilisers, due to the relatively high complexity of stabilised organic matter, which makes it fairly reluctant to decomposition and prone to being humified. Conversion into grassland is the most effective carbon mitigation option, which endorses the main conclusion by Smith et al. (2000a, b) implying that putting surplus arable land into long-term alternative climate change abatement is the most effective land use option in agriculture.

Compared to the business-as-usual scenarios (Chapter 2.6), the *changes* in carbon fluxes owing to the different measures or climate change effects evaluated in this study were considerably less sensitive to the initial soil carbon content. The reason for this is that they are the resultant of the difference between two carbon fluxes calculated with the same initial value of soil carbon content. This favourably affects the robustness of the estimates and the quantification of regional differences.

Interannual variability in climate affects yields and hence, the amount of carbon returned to the soil, and also decomposition rates. As illustrated by Vleeshouwers and Verhagen (2002), the effect of leaving behind and incorporating straw residues varies. Even when averaged over a period of 5 years, natural interannual variation in prevailing conditions and crop yields may cause substantial variation in the effect of the measure. This raises the question whether it may be more appropriate to reward an activity aimed at the increase of carbon rather than to reward its actual effect on the carbon stock in the field, since the latter may partly depend on the conditions during the commitment period that cannot be influenced by farmers. Additionally, such an approach may also be more pragmatic because it may be difficult to show the actual effect on the carbon stock.

3.4 Factors limiting carbon sequestration in soils

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 with time need to be considered. Soil carbon sequestration is non-linear. Long-term experiments show us that increases in soil carbon are often greatest soon after a land-use / land-management change is implemented (Smith et al., 1997). 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 (IPCC: Watson et al., 2000). Whilst soil carbon levels may not reach a new equilibrium until 100 years after land-use / land-management change (e.g. Smith et al., 1996), carbon sequestration potential may be minimal after 20 years; 20 years is the value used by the IPCC for national greenhouse gas inventories (IPCC, 1997). Soil carbon sequestration does not, therefore, have limitless potential to offset CO_2 emissions; the yearly benefits will continue for about 20 years.

In this context it is important to consider the long-term efficiency of measures with respect to carbon sequestration as well as to costs. If it is assumed that organic material, such as compost, manure or sewage sludge, is continuously applied over an extended period at a constant cost, the cost efficiency of this measure would be initially high due to a high sequestration rate. The cost efficiency is expected to decline with lowered sequestration rate. Finally, the measure, and the costs linked to it, have to be maintained only to keep an elevated carbon level in the soil, without a continued net sequestration.

Non-permanence

Soil carbon sequestered in arable soils is non-permanent. By changing agricultural management or land-use, soil carbon is lost more rapidly than it accumulates (Smith et al., 1996). 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 (Smith et al., 1997), much of the benefit of reduced tillage is lost by ploughing, when compared to a permanent management change. The impacts of such practices can be estimated; for example permanent set-aside or zero-tillage might result in a carbon sequestration potential of 1.42 t CO_2 ha^{-1} y^{-1}, whilst set-aside or zero-till which is ploughed every 3 to 4 years would have a carbon sequestration potential that is much lower. For practical purposes, however, in order to implement a meaningful carbon sequestration policy on agricultural land, management changes must be permanent.

Availability of land and adoption of measures

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). For instance, for zero tillage, the suitable area depends upon the workability of the soil, which will depend on soil texture (some soils like heavy clays are not suitable). In Table 3 below, the total estimated carbon sequestration potential is presented for Europe of each of the measures in Table 2, taking account of the limitation in suitable land / resources etc. Where possible, the potential attainable by the end of the first Kyoto Commitment Period (2012) is estimated, though more work needs to be done in estimating social and economic limitations to the implementation of these measures.

Also, with restrictions in applications of nutrients under the Nitrates Directive (and possible further measures under the Water Framework Directive) there may be limits to the amounts of compost, manure and sewage sludge that can be applied to land. The loading rates for organic material in agricultural land, as proposed in Table 3, still fall within the limit loads acceptable under the Nitrates Directive, however, it is important that organic nitrogen input is accounted for and chemical nitrogen fertiliser application is reduced accordingly.

Table 3 Total carbon sequestration potential of measures for increasing soil carbon stocks in agricultural soils for Europe (EU15) and limiting factors. The potential indicated is to a large extent non-additive. GHGs other than CO_2 are included on all measures considered in Smith et al. (2000, 2001).

Measure	Total soil carbon sequestration potential if all agric. land used (Mt CO_2 y^{-1})	Limiting factor	Soil carbon sequestration potential (Mt CO_2 y^{-1}) given limitation	Soil carbon sequestration potential (Mt CO_2 y^{-1}) by 2012	Reference / notes
Crop-land					
Zero-tillage	103	Suitable land = 63 Mha	89.28	8.93	1
Reduced-tillage	< 103	Suitable land = 63 Mha	<89.28	<8.93	2
Set-aside	103	<10% of arable land; < 7.3 Mha	Maximum = 8.09	0	3
Perennial grasses and permanent crops	165	No incentives to grow more	0?	0?	4
Deep-rooting crops	165	Research and breeding needed for annual crops	0?	0?	4
Animal manure	100	Manure available = 385 Mt dm y^{-1}	86.83	?	5
Crop residues	185	Surplus straw = 5.3 Mt dm y^{-1}	90.46	?	6
Sewage sludge	69	Sewage sludge = 71 Mt dm y^{-1} 8.3 Mt dm y^{-1} available in the mid term (2005)	6.30	?	7
Composting	100	Compost producible at present = 160 Mt dm y^{-1} = enough to cover 8 000 000 ha at 20 t ha^{-1} y^{-1} - alternative estimate: Compostable materials potentially available in MSW = 60-105 Mt y^{-1}= potential production of composted materials = 21-37 Mt y^{-1}, (i.e. 13-22 Mt y^{-1} d.m.) enough to cover 1.3 – 2.2 M ha at 10 t ha^{-1} y^{-1}. Figures include processing of biowaste from agro-industrial by-products, but neither manure nor crop residues.	11	11?	8
Improved rotations	0	>0	0?	0?	9
Fertilisation	0	0	0	0	10
Irrigation	0	0	0	0	11
Bioenergy crops	165	Assuming food demand remains the same – can	12.94	2.6	12

		use only current set-aside = 7.3 Mha. This calculation was based on the assumption that bioenergy crops could be grown on set aside land. This possibility is not foreseen in the latest CAP reform proposal (COM (2003) 23 final).			
Extensification	144	Assuming food demand remains the same – can use current set-aside to extensify about 30% of arable agriculture = 20 Mha	41.63	?	13
Organic farming	0-144	Currently 2% or arable area = 1.5 Mha. Market share could increase to 10% = 7.3 Mha.	14.4	14.4	14
Convert arable to Woodland	165	Assuming food demand remains the same – can use only current compulsory set-aside = 7.3 Mha	12.94	Max. 12.94	15
Convert arable to grassland	140	Assuming food demand remains the same – can use only current compulsory set-aside = 7.3Mha	14	0	16
Convert grassland to arable	-266	Land-use change since 1990 calculated as 2.7 Mha	-10 (since 1990). Future = 0	0	17
Convert permanent crops to arable	-42.5	Land-use change since 1990 calculated as 0.4 Mha (Figure 4)	-1.46 (since 1990)	0	18
Convert woodland to arable	=>-266	Negligible land-use change since 1990	0	0	19
Grazing land					
Livestock Management	??	??	??	??	20
Cutting method and frequency	?	?	?	?	?
Fertilisation	0	0	0	0	21
Fire protection	??	??	??	??	22
Revegetation					
Abandoned Arable land	165	Assuming food demand remains the same – can use only current obligatory set-aside = 7.3 Mha	16.52	Max. 16.52	23
Farmed organic soils					
Protection and restoration	>36	Assuming all cultivated organic soils are restored	>36	>36	24
Avoid row crops and	0	High yields and financial returns for sugar beets	0?	0?	24

tubers	GHG: 2	and potatoes, no incentive			
Avoid deep ploughing	3 GHG: 3	Traditional land-use system, no incentive	0?	0?	24
More shallow water table	36 GHG: 36	Possibly attractive on grassland when new melioration is needed – 50 % of grassland area during first commitment period = 1.5 Mha	15	15	24
Convert arable to grassland	3 GHG: 3	No incentive	0?	0?	24
Convert arable to woodland	2 GHG: 3	Subsidies compensate income losses – adoption rate max. 50 % of arable area = 0.3 Mha	1	1	24
New crops on restored wetlands from arable	8 GHG: 7	Needs more research and demonstration	0?	0?	24
New crops on restored wetlands from grassland	24 GHG: 18	Needs more research and demonstration	0?	0?	24
Sheep grazing on undrained peatland	>24 GHG: >30	Common practice in Scotland and Ireland, could be linked to subsidies for extensification – adoption rate probably 50 % of grassland area – 1.5 Mha	12	12	24
Abandon for conservation	>24 GHG: >30	No incentive	0?	0?	24

References / notes:

1. Total figure for EU15 calculated from figures in Smith *et al.* (2000). Suitable land area from Smith *et al.* (1998). Estimated maximum of 10% adoption before 2008 estimated from uptake in the USA since 1970 in Lal *et al.* (1998). Some experts stated that no-tillage accumulation of soil organic carbon is over-estimated in the literature, and no-tillage may be no real option in European humid climate.
2. Total figure for EU15 estimated to be lower than figure for zero-till calculated from figures in Smith *et al.* (2000). Suitable land area from Smith *et al.* (1998). Estimated maximum of 10% adoption before 2008 estimated from uptake in the USA since 1970 in Lal *et al.* (1998).
3. Set-aside has decreased during the 1990s. If at current levels (10% of arable area – Smith *et al.*, 2000) the potential would be 8 930 Kt CO_2 y^{-1}, but is likely to be negligible by 2012.
4. Total figure for EU15 based on per hectare value assumed to be the same as for bioenergy crops. There are no special incentives for perennial crops so the prevalence of perennial crops is unlikely to increase.
5. Total figure for EU15 calculated from figures in Smith *et al.* (2000). Total amount of manure available from Smith *et al.* (1997)
6. Total figure for EU15 calculated from figures in Smith *et al.* (2000). Total amount of surplus cereal straw available from Smith *et al.* (1997)

7. Total figure for EU15 calculated from figures in Smith *et al.* (2000). Total amount of sewage sludge available from Smith *et al.* (1997) and European Commission (1998)
8. Total figure for EU15 based on per hectare value assumed to be the same as animal manure, though the stabilisation of organic matter that occurs throughout composting should affect positively its tendency to humify instead of being mineralised. Values of first figure: Total compost dry matter excluding sewage sludge derived compost figure of 160 Mt dm y^{-1} from Hargreaves (2001). For the second figure, total compostable materials in MSW (excluding sewage sludge and agroindustrial by-products) from DHV (1997) and EEA-ETC waste (2002), do not include other biodegradable materials, such as paper, which are compostable but usually get recycled as secondary raw materials in the same sector. No reliable and comparable EU-wide estimate is available for agroindustrial by-products (dairy industry, wood processing industry, paper factories, wine processing industry, etc.) though in some country-specific surveys the quantities of compostable waste thereof is reported at 1 upper order of magnitude. This would imply a ten-fold magnitude, or so, of achievable effects.
   As the limiting factor for this measure is the amount of compost producible, the overall sequestration potential is rather independent on the loading rate per area.
9. Assumed negligible benefit – see Table 2.
10. Assumed negligible benefit – see Table 2.
11. Assumed negligible benefit – see Table 2.
12. Total figure for and area available in EU15 calculated from figures in Smith *et al.* (2000). Uptake assumed to be 20% of maximum potential by 2008 as for the UK (UNFCCC, 2001)
13. Total figure for and area available in EU15 calculated from figures in Smith *et al.* (2000).
14. Range assuming per hectare figures of Table 2. Total area currently under organic production (2%) in EU15 taken from values given in Policy Chapter (see later), total area from those calculated from Smith *et al.* (2000). Assuming that organic farming would remain profitable only if less than 10% of farm products were produced organically.
15. Total figure for and area available in EU15 calculated from figures in Smith *et al.* (2000) and from ECCP (2001).
16. Total figure for EU15 from Vleeshouwers & Verhagen (2002). Available area (<10% set aside) from Smith *et al.* (2000). Livestock numbers are falling; unlikely to be greater demand for new grassland.
17. Total area available in EU15 calculated from figures in Smith *et al.* (2000) and Eurostat (1994). About 3 Mha of permanent pasture have been lost since 1990 (see graph in Policy Chapter). 60% of the 0.5 Mha afforested between 1993 and 1997 under regulation 2080/92 came from permanent grassland = 0.3 Mha. This leaves a total area of grassland to arable conversion of about 2.7 Mha from 1990 to present. Further change from grassland to arable is unlikely to occur due to stable food demand.
18. Loss of area of permanent crops (vineyards, olives, and orchards) does not necessarily mean conversion to arable land; the land could be abandoned and revegetated. Therefore worst-case estimate.
19. Loss of carbon when converting woodland to arable at least that of converting grassland to arable. Actually, afforestation has occurred (see Policy Chapter) meaning that the net change will be positive.
20. No reliable data
21. Assumed negligible benefit – see Table 2.

22. No reliable data
23. Total figure for EU15 based on per hectare value assumed to be the same as Rothamsted Geescroft natural regeneration (Poulton, 1996). Same figure as for conversion of arable to woodland.
24. Calculated by A. Freibauer. GHG: Effect including N_2O and CH_4, given as CO_2-equivalents.

3.5 Potential environmental side effects of soil carbon sequestration measures

Table 4 Potential environmental side effects of the soil carbon sequestration options

Measure	Potential environmental side effects
Crop-land	
Zero-tillage	Effects are regionally specific. Soil structure improves under most conditions, but increased bulk density may lead to reduced rootability and infiltration in some cases. Reduction of soil erosion. Risk of increase in pesticide usage. Generally less fossil fuel used (included in calculations). N_2O emissions may increase under wet soil conditions, as soils may become more anaerobic leading to more N_2O production from denitrification. When these potential increases in N_2O are converted to carbon equivalents and included in the calculations, the total mitigation effect in terms of the global warming potential is reduced by about 50-60% compared to when only soil carbon sequestration is considered (Smith et al., 2001). Positive effects from increased organic matter, such as increased water retention capacity and increased binding capacity for pollutants. However, as the soil drainage is not disrupted as in ploughed fields, there is a potential for rapid or by-pass flow through continuous macropores leading to potentially increased leaching of contaminants. Should be combined with adequate crop rotation to reduce negative consequences. Potential positive impact on biodiversity in the soil.
Reduced-tillage	As for zero tillage. European climate and farm conditions favour reduced tillage, which has also less negative side effects.
Set-aside	More weeds in years following set-aside – more herbicide usage possible. Improved biodiversity for some species possible. Use of set-aside as buffer strips along watercourses could reduce soil erosion, improve water quality and increase biodiversity. Requires long-term set-a-side and careful management. If brought back into production stored C will be rapidly lost – therefore needs to be permanent.
Perennial grasses and permanent crops	Improved biodiversity for some species possible. If these are grazed there will be additional CH_4 and N_2O emissions to offset gains.
Deep-rooting crops	Improved continuity of soil pores to greater depth, enhanced deep infiltration. May lead to continuous pores to greater depths increasing leaching of nutrients and rapid movement of water.
Animal manure	Potentially a number of environmental side effects associated with the significantly increased transport required for this measure (Smith & Smith, 2000). Increased transport emissions, which are about 30% of sequestered carbon if average distance moved is 100km. But increased demand for fuel, increased particulate losses from combustion of fuel, if fitted with catalytic converters, increased ammonia and other gaseous emissions from transport etc. (ECCP, 2001). Increased pollution incident if the manure was not managed properly. Biosecurity concerns of taking manure onto arable farms if they also have livestock – particularly in terms of pig farms. On the positive side possible trace gas benefits (compared to applying the manure to grasslands) and improved soil structure and water holding capacity (Smith et al., 2001) Additions of animal manure will improve the organic matter of the soil,

	contributing to better structure, reduced erosion, and run off (potentially reducing flooding in the long-term), and improving water quality. Animal manure, in the same way as other organic material applied on agricultural land, is a source of N, which can replace chemical N fertiliser. This additional input has to be accounted for by the farmer to reduce oversupply of N and leaching. In practice, farmers appear not to sufficiently account for the N applied in organic forms and tend not to reduce mineral fertilisation rate. More dissemination and practical training may be needed.
Crop residues	Additional energy costs required for chopping and incorporating residues.
Sewage sludge	Potentially negative environmental effects, such as the build-up of heavy metals and organic pollutants is prevented by applying sewage sludge below the safe EU limits as defined by Directive 86/278/EEC (Smith et al., 2001). The Sludge Directive is currently being revised (Dir. 86/278/EEC), and "pollution prevention programs" are defined, whereby the strategy aims at a reduction of maximum allowable concentrations (in sludge) and loads (onto the soil) of PTE's; the reduction of maximum allowable concentrations and loads is much sharper for most hazardous substances, such as Hg (10-fold reduction) and Cd (20-fold reduction)
Composting	Environmental benefits of compost application on the field include the avoided use of chemical fertilisers (reduction of N_2O emissions from production and use of N fertilisers) and pesticides, improved tilth, positive effect on trace minerals. Compared to mineral N fertilisers N_2O emission is reduced, due to the slower release of N that might therefore be better taken up by roots. To estimate the complete N_2O balance it would be necessary to study the N_2O emission of organic material, which is not composted, and to compare it with that of composted material. Currently, data is lacking for such a comparison. Possible release of methane during composting has been questioned, and is not likely in well-managed processes due to the aerobic nature of metabolic pathways. N_2O emissions are fairly negligible (3-3.5 kg CO_2-eq/t). However, NH_3 emissions can be high. The application of safe composted materials is being ensured in many countries by tight regulations for composted materials which only allow the application onto croplands of composts deriving from source separated waste; to ensure and enforce such a strategy EU-wide a Directive is due to be proposed by 2004, according to a deadline set in the EC Communication on the Soil Strategy. Regulation 1774/2002 stipulates rules concerning animal by-products in order to ensure biosecurity issues. The application of these rules should effectively prevent risks when animal by-products are composted. Benefit of reduced pathogens in stored / composted materials. If manure is composted, N_2O and methane emission can be reduced.
Improved rotations	If carefully planned, could reduce nitrate leaching.
Fertilisation	Increased N_2O emissions with chemical N fertilisers due to addition of extra reactive N to the soil. CO_2 carbon costs of chemical fertiliser production can be greater than the soil carbon sequestration benefit (Schlesinger, 1999).
Irrigation	CO_2 carbon costs of pumping irrigation water can be greater than the soil carbon sequestration benefit (Schlesinger, 1999). Any usage of irrigation measures needs to be carried-out in clear co-ordination with the economic needs assessments and river basin management requirements as defined under the Water Framework Directive.
Bioenergy crops	This is a measure that the UK Government believes can mitigate emissions of CO_2 from fossil fuels and has introduced the Energy Crops Scheme under the England Rural Development Programme to support these activities. Expenditure of £30m over the seven-year life of the programme will support planting of crops and setting up of producer groups for short-rotation coppice and *Miscanthus* growers. Because the biomass fuel chain results only in some GHG emissions (sometimes nearly C-neutral-depending on the biomass chain, considered), energy crops can make a significant contribution to Government targets on renewable energy and climate change. The Prime Minister recently

	announced a further £50m support for renewable energy from biomass and offshore wind. This is not carbon sequestration since the carbon is rapidly burnt to substitute for fossil fuels. The IPCC calls this "carbon substitution", replacing fossil carbon by "recent "carbon (ECCP, 2001). May also improve biodiversity and leisure and amenity value of the land (Smith et al., 2001). If applied on existing wetland/grassland sites already high in carbon the hydrology may be negatively affected with a knock on effect of reducing C in soils. Compared to set aside conditions, there is an increased nutrient demand, with corresponding CO_2 and N_2O emissions.
Extensification	Wildlife benefits, animal welfare benefits, improved soil structure (Smith et al., 2001)
Organic farming	Potential benefits due to reduced fertiliser production (hence less CO_2 produced), more fuel carbon used as physical methods are used to reduce weeds in place of herbicides. Possible wildlife benefits, animal welfare benefits. Improved soil structure. Potentially more nitrate leaching and N_2O emissions (depending on time of application of manure). Some experts doubt the latter effect.
Convert arable to woodland	Benefits potentially high if afforestation is sensitive to regional habitats and landscapes. Biodiversity and landscape will not be improved by commercial monocultures. This requires abandonment of agricultural land. Afforestation is already part of agroenvironmental schemes in some member states (ECCP, 2001). May improve biodiversity and leisure and amenity value of the land (Smith et al., 2001).
Convert arable to grassland	Potentially high benefits depending on end use and type of restored grassland habitat, in particular for biodiversity. Semi-natural grasslands are among the most biodiversity rich areas of the enlarged EU. May reduce leaching. In longer-term possible increases in N_2O emissions and CH_4 if grazed.
Convert grassland to arable	Negative environmental impact. Lose soil carbon. Of minor importance. The arable land area has been largely fixed since 1992.
Convert permanent crops to arable	Negative environmental impact. Lose soil carbon
Convert woodland to arable	Negative environmental impact. Lose soil carbon
Grazing land	
Livestock management	May reduce soil degradation and compaction. Potential to manage livestock so they are not on land where risk of run-off and therefore pollution from manure is high.
Cutting method and frequency	May enhance productivity.
Fertilisation	Increased N_2O emissions due to addition of extra reactive N to the soil. CO_2 carbon costs of fertiliser production can be greater than the soil carbon sequestration benefit (Schlesinger, 1999).
Fire protection	Improve biodiversity in fire prone areas. In some regions burning is used for fertility building and improving soil structure.
Revegetation	
Abandoned	Same as for “convert arable to woodland”

arable land	
Farmed organic soils	
Protection	The potential for GHG reduction is high. If the reduction of N_2O and CO_2 emissions originally emitted from peat oxidation is included, the overall effect is >5000 Kt CO_2-equivalents y^{-1} if an adoption on 10% of farmed peatlands of either of the measures 1) no roots and tubers, 2) abandon tillage, 3) recultivation, is achieved (ECCP, 2001).
Avoid row crops and tubers	Frequent and intensive soil disturbance under vegetables, potatoes, and sugar beets and enhances N mineralisation (Klemedtsson et al., 1999). In several Swedish studies, N_2O emissions were higher than under cereals.
Avoid deep ploughing	Avoid a pulse in soil aeration. However, this means to abandon the traditional practice in many regions with a sandy mineral layer underneath the peat and makes the soil less workable (see chapter 2.3).
More shallow water table	This will restrict the choice of arable crops and will probably be restricted to grasslands. Biodiversity benefits from increased wet grassland sites (previously been lost). May increase hydrological connectivity to catchment drainage system so increase potential of pollution. May increase or decrease potential of flooding elsewhere in catchment. Wetter conditions at soil surface may increase N_2O emissions.
Convert arable to grassland	Best in conjunction with a more shallow water table.
Convert arable to woodland	Afforestation of peat soils under arable crops only if provided that a shallower water table than before is maintained. There will be also some extra benefit through carbon sequestration in wood and wood products (Cannell and Milne, 1995). The afforestation of grasslands will only show long-term benefits. However, Swedish studies suggest that in the first years of afforestation greenhouse gas emissions may be higher (Maljanen et al., 2001). Also Birch planted as short-rotation coppice increased carbon losses and greenhouse gas emissions due to the lowering of the water table by intensive respiration (Å. Kasimir Klemedtsson, pers. comm. 2001). Further research is needed before afforestation of peat soils can be recommended as option with short-term and long-term benefits.
New crops on restored wetlands from arable	*Typha* produced for industrial raw material on rewetted, formerly drained, fens reduces the emission of greenhouse gases, retains water and probably reactivates the function of peatlands as a sink of nutrients in the landscape (Wild et al. 2001). However, economic viability and large-scale applicability still remain to be proven.
New crops on restored wetlands from grassland	Same as for New crops on restored wetlands from arable.
Sheep grazing on undrained peatland	Abandon drainage and use native grass sod for extensive sheep grazing. Sheep-grazing and rotational burning are widely practised on blanket peat moorlands in the United Kingdom. In a study of Garnett et al. (2000), light sheep-grazing did not affect rates of carbon accumulation over 30 years in blanket peat, but decadal burning of moorland reduced C sequestration. High livestock may have a negative impact on CO_2 emission from peatland.
Abandon for conservation	Peatlands need decades to recover from drainage and to regain the original vegetation cover. Nevertheless, the restoration will rapidly stop peat oxidation. Manifold conservation and recreation benefits.

3.6 Implementation of measures under Article 3.4 of the Kyoto Protocol

To be successful agricultural measures to sequester carbon must meet the following requirements: be effective and cost-competitive, provide stable storage, and be environmentally friendly. There is a priori no limit on the surface of agricultural land that can be used as a sink. The only limitation is the application of a so-called net-net approach for agricultural activities like cropland management, grazing land management and revegetation. Net-net accounting relies to the difference in the net emissions or removals during the commitment period and the net removals in the base year (1990 levels). Hence, also carbon sequestration rates in 1990 and greenhouse gas emissions have to be calculated in retrospective. The Intergovernmental Panel on Climate Change (IPCC) is going to prepare the methodology of estimating the 1990 emission levels and controlling / monitoring the reduction potential of different measures. The rules and guidelines relating to the agricultural measures have to be in line with the definitions and rules set by the Conference Of Parties (FCCC/2001/13), i.e. measures need to be measurable, transparent and verifiable, "direct human-induced", and occur since 1990.

Natural and indirect effects

Beside direct human induced measure natural and indirect human induced effects will affect the carbon dynamics in agricultural soils. The IPCC Special report on Land use, Land use Change and Forestry (Watson et al., 2000) already indicated the difficult task to distinguish between the portion of the observed stock change that is directly human-induced from that portion that is caused by indirect and natural factors.

Also human induced measures such as improved crop and soil management may fall under this definition when these measures are already implemented for other reasons than carbon sequestration, e.g. organic farming may be promoted for other good reasons but also positively affect the carbon budget. Such activities can be regarded as not being additional and therefore may not be eligible in the crediting system if the European interpretation of "additionality" is adopted. In contrast, other parties use the term in the sense of measures other than afforestation and reforestation. The term "additionality" needs to be defined in an unambiguous way before the carbon sequestration potential under Article 3.4 can be properly estimated. For the first commitment period, the "net-net" accounting replaces the distinction between direct human-induced and other effects. The question is, however, still relevant since the negotiations about a more science-based accounting scheme for subsequent commitment periods will start this autumn.

Because the range of possible baselines is large and in most cases regional only those related to biophysical processes are listed here.

N deposition results in a higher carbon sequestering potential (White et al., 2000).

Rising CO_2 concentration in the atmosphere. The amount of total crop biomass increases with increasing CO_2 concentration. The annual increase was estimated at 0.2 % (Goudriaan and Unsworth, 1990). The decomposition of organic matter in the soil is not affected by the elevated CO_2 concentration in the atmosphere (Sadowsky and Schortemeyer, 1997; Van Ginkel *et al*., 1997).

Rising temperature will at the lower range negatively affect the decomposition of soil organic matter.

Changes in precipitation regime will affect the decomposition of soil organic matter. Wetter conditions will have a positive effect on the carbon sequestration potential.

Baseline

Whether agricultural soils are a sink or source of carbon critically depends on the actual organic matter content in the soil (Figure 7).

Establishing a baseline of carbon in the topsoil for 1990 is therefore crucial when establishing whether agricultural land was a sink or source in 1990. When assessing the overall effects of mitigation options (as presented in Table 3) this question is of minor importance. However, considered on a local scale the effects of mitigation options can depend on the actual soil organic carbon content.

To establish a baseline at European level the policy process should use the best soil data available. At present there are no better or more comprehensive data than those available from the European Soil Database at 1:1,000,000 scale (King et al., 1995; Le Bas et al., 1998), since these data are harmonised according to international standards of soil nomenclature and classification (FAO). For policy implementation in future, more detailed data (preferably at 1:250,000 scale) will be needed but, for the time being at least, the European Soil Database should be the basis for setting the baseline.

In the absence of organic carbon contents, measured according to a standard analytical procedure for soils across the whole of Europe, a series of pedotransfer rules were developed (Van Ranst 1995; Daroussin and King, 1997), under the auspices the European Soil Bureau (ESB), and these have been applied to the European Soil Database for estimating baseline organic carbon content in topsoils in Europe. The first results of this approach are described by Rusco et al. (2001) and they show that the application of a standard pedotransfer rule for the whole of Europe introduces significant errors in the estimated organic carbon contents for some parts of the continent. Consequently, a more complex procedure has been adopted to refine the previous estimates (Rusco et al., 2003 - in preparation). This involves incorporates CORINE land cover data at 1km resolution (Hiederer, pers. comm.) and climate data from the MARS Project (Vossen and Meyer-Roux, 1995).

The CORINE+ land use data derive mainly from 1988 and the soil data derive from the updating of the European Soil Database that was made between 1990 and 1994. The climate data are derived from MARS agroclimatic database for the period 1975-1995. Therefore the resulting map of organic carbon in topsoils will provide the best estimated organic carbon ‘baseline‘ for 1990.

It is also important to look at changes in management practices over time (e.g. increase of fertiliser in organic farming systems). These, however, are region or country specific and difficult to quantify. Area specific data related to land use and carbon are presented in chapter 2. Residue and (organic) fertiliser management largely determine the baseline in agriculture. Uncertainties of estimates made by Vleeshouwers & Verhagen (2002) were high (Table 5). Assuming the use of inorganic fertiliser and removal of crop residuals from the field, Vleeshouwers and Verhagen (2002) calculated average carbon fluxes under the business as usual scenario in the 2008-2012 commitment period, per hectare values for grassland fluxes of carbon min: -6.63, max: 8.47, mean: 2.20, with a standard deviation of 2.37 t CO_2 ha^{-1} y^{-1}. Equivalent figures for arable land were min: -10.76, max: 1.12, mean: -3.05 with a standard deviation of 1.47 t CO_2 ha^{-1} y^{-1}. (Table 5).

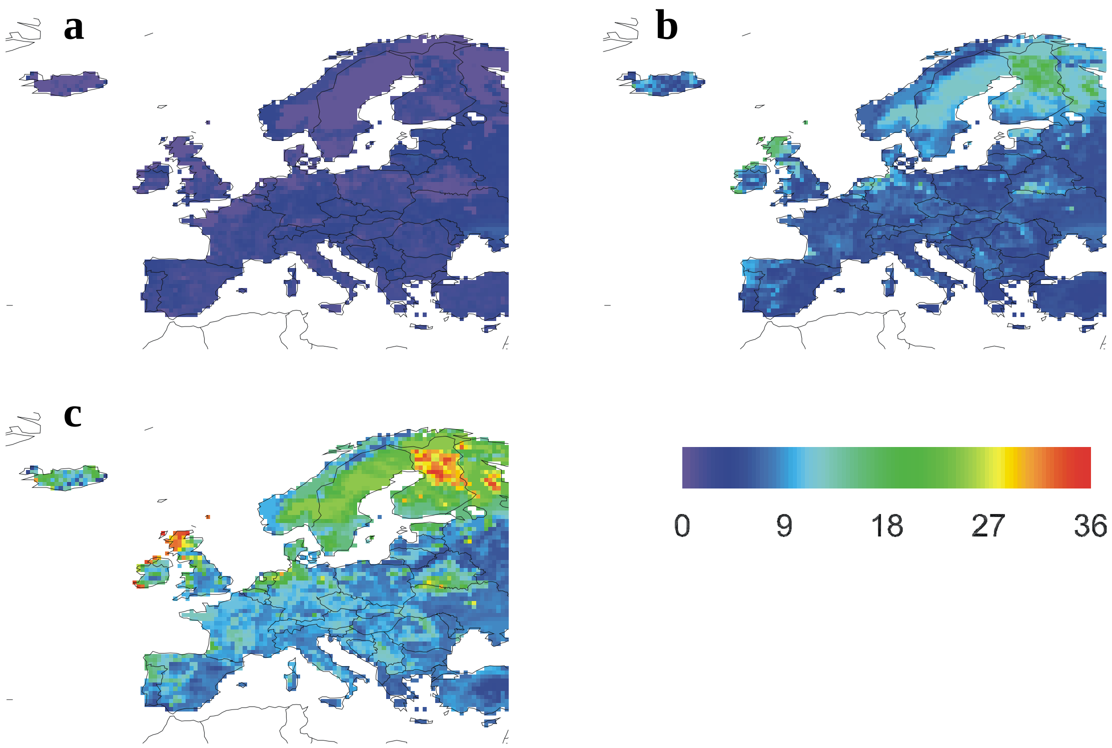


Figure 7 *Carbon contents in soil organic matter (kg m^{-2}) in the 0-30 cm layer reported by IGPB-DIS; (a) mean value minus standard deviation, (b) mean value, (c) mean value plus standard deviation.*

However, for agricultural management under the Kyoto Protocol, the baseline required does not refer to carbon stocks as for forest, but has to provide the carbon FLUXES in 1990. Therefore, additional efforts are needed to establish baseline FLUXES, by compiling regional data on typical land management (fertilisation, manure application, organic amendments, tillage if possible) and GIS-based modelling.

Table 5 Yearly carbon fluxes in EU15 under business as usual in the first commitment period (Vleeshouwers & Verhagen, 2002)

Type of Agricultural land	**Area (ha)**	**Per ha yearly C fluxes ($t\ CO_2\ ha^{-1}\ y^{-1}$) [1]**				**Total yearly flux for EU15 ($Mt\ CO_2\ y^{-1}$) [2]**			
		Min	**Max**	**Mean**	**SD**	**Min**	**Max**	**Mean**	**SD**
Grassland	4.93E+07	-6.63	8.47	2.20	2.37	-327	418	109	117
Arable	9.31E+07	-10.76	1.12	-3.05	1.47	-1001	104	-284	137
All agriculture	1.42E+08					-1328	522	-176	137
Type of Measure	**Area (ha) 9.31E+07**	**Per ha yearly C fluxes ($t\ CO_2\ ha^{-1}\ y^{-1}$) [1]**				**Total yearly flux for EU15 ($Mt\ CO_2\ y^{-1}$) [2]**			
		Min	**Max**	**Mean**	**SD**	**Min**	**Max**	**Mean**	**SD**
conversion arable to grass		2.31	11.23	7.03	2.08	215	1046	655	193
no-tillage		0.00	2.63	1.05	0.32	0	245	98	30
incorporation of straw		-1.12	1.10	0.78	0.28	-104	103	73	26
application of FYM		-2.54	11.76	5.37	1.64	-236	1094	500	153

[1] Figures are mean yearly values for the first Kyoto commitment period (2008-2012) under business as usual scenario

[2] Tg = 10^{12}g

[3] Standard Deviation (SD) from arable flux estimates

Yield data used were on a whole country basis (FAO-data) and soil data (C and texture) were taken from the IGDP-DIS soil map.

Variability and uncertainty

Ecosystem productivity as well as organic matter decomposition are strongly determined by environmental conditions. Weather (temperature, precipitation), soil type and past events will have a direct effect on the carbon sequestering potential. This climate variability is reflected in the decomposition rate (Figure 8).

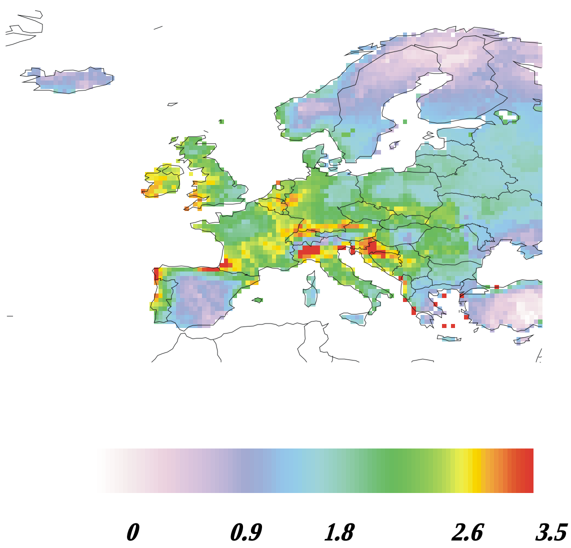


Figure 8 Annual relative decomposition rates (% y^{-1}) calculated by CESAR (Vleeshouwers and Verhagen, 2000). This figure was questioned by some experts, who doubt that decomposition rates in southern Spain are less than in Piemonte, Slovenia and Croatia. It was advised that the map should be much more closely related to a map of accumulated temperature.

Climatic conditions, especially temperature and rainfall, exert a dominant influence on the amounts of carbon and nitrogen in organic matter found in soils. When moving from a warmer to a cooler climate, the organic carbon and nitrogen of comparable soils tend to increase. This is because generally the decomposition of organic matter is accelerated in warm climates while a lower rate of decomposition is the case for cool regions. In summary, within belts of uniform moisture conditions and comparable vegetation, the average total organic matter and nitrogen increase from two to three times for each 10 deg. C fall in mean temperature (Buckman and Brady, 1960, p.152).

High decomposition rates particularly occur in regions where high temperatures in summer coincide with moist conditions. Low decomposition rates are associated with low temperatures and wet conditions as found in Northern Europe (see Figure 8).

Ecosystem productivity or crop yields tend to be higher in Western Europe. Regional differences do exist and are important, the FAO data set however contains country specific data without any sub country specific information. For grassland production only a limited amount of data is available adding to the large uncertainty associated with the spatial variability.

In general, low crop yields, high soil carbon contents and high soil organic matter decomposition rates enhance the loss of carbon from agricultural soils.

Management practices also vary from place to place, most important for carbon sequestration are soil management / tillage, the use of organic manure and sewage sludge. At a European scale no information is available on regional preferences.

4 Monitoring and Verification of Carbon Sequestration in Agricultural Soils

4.1 Definition of verification

According to the IPCC Good Practice Guidelines (Penman et al., 2000), verification refers to the activities and procedures that can be followed to establish the reliability of the data. This usually means checking the data against empirical data or independently compiled estimates.

For verification of Article 3.4 activities, estimates are required for carbon fluxes and / or changes in carbon stocks that are independent of those used in a party's national report. 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 decide is acceptable in terms of verifiability (Smith 2001):

- At its most stringent, verifiability would entail the sampling of each georeferenced piece of land subject to an Article 3.4 activity at the beginning and end of a commitment period, using a sampling regime that gives adequate statistical power. Soil and vegetation samples and records would be archived and the data from each piece of land aggregated to produce a national figure. Separate methods would be required to deliver a second set of independent verification data. Such an undertaking at the national level would be prohibitively expensive.
- At its least stringent, verifiability would entail the reporting of areas under a given practice (without georeferencing) and the use of default values for a carbon stock change for each practice, to infer a change for all areas under that practice.
- Intermediate in the range of verifiability is a scheme in which areas under a given practice are georeferenced (from remote sensing or ground survey), carbon changes are derived from controlled experiments on representative climatic regions and on representative soils (or modelled using a well-evaluated, well-documented, archived model) and intensively studied benchmark sites are available for verification.
- If the parties decide on a stringent level of verifiability, Article 3.4 is at present, and is likely to remain in the future, unverifiable. If less stringent levels of verifiability are adopted, a low level of verifiability might be achieved by most parties by the beginning of the first commitment period (2008-2012).

A three-level monitoring and verification framework for Article 3.4 has been agreed (as quoted in Smith 2001):

***Level 1**:* Monitoring and self-reporting by parties on emissions and removals of greenhouse gases by Article 3.4 activities according to IPCC reporting guidelines and good practice guidelines

***Level 2**:* Validation and verification at the national level, including by peer and public review

Level 3: Validation and verification at the international level by Expert Review Teams according to Article 8 of the protocol.

Against this background and without anticipating the results of the IPCC process, some general minimum requirements for monitoring can be identified. These form a synthesis of the IPCC Special Report on LULUCF (Watson et al. 2000), reviews of Post et al. (2001) and a VERTIC Briefing Paper (Smith, 2001) and experiences in the CarboEurope cluster of EU research projects.

We assume here an intermediate stringency in which national reporting will be based on either default values for carbon sequestration or regional factors for carbon sequestration derived from benchmark sites. Verification then means monitoring by additional independent measurements in conjunction with modelling, ground-based and airborne observations.

4.2 Monitoring requirements for reporting and verification

In order to account for the spatial and temporal heterogeneity of soil properties and in order to determine small changes against a high carbon stock background, monitoring must comprise field measurements on permanent sample plots in conjunction with a survey of land management, models in a GIS framework and remote sensing products. These serve for the triple purposes of creating an adequate inventory of soil carbon stocks, the quantification of carbon stock changes and of greenhouse gas emissions during the commitment period and their attribution to additional human-induced activities under Article 3.4 (Table 6).

Inventory of soil carbon stocks

Existing soil maps need further refinement (e.g. Figure 7) in order to provide a reliable estimate of soil carbon and nitrogen stocks under different land use and management. A carefully designed soil monitoring network should be stratified by land use, management, soil type, and climate region (concerning this point, information is available from the JRC from the MARS agoclimatic database.), and use geostatistical approaches to capture plot-scale spatial variability. In order to avoid temporal bias through seasonal variation in soil properties, sampling should take place in harmonised time windows (e.g. winter). Samples should be taken on a volumetric basis (or, alternatively, on a mass basis) including the litter layer and an intensive stratification in the 0-30 cm layer (e.g. 0-5 cm, 5-10 cm, 10-20 cm, 20-30 cm) and wider steps for sampling down to 1 m or more in order to make sure that carbon sequestration in topsoil is not compensated by carbon losses deeper in the profile.

Carbon sequestration and other greenhouse gas emissions

As outlined in the IPCC Special Report on LULUCF (Watson et al. 2000), two types of methods are used to measure losses or accumulations of carbon on land: those that measure stocks of carbon and those that measure fluxes of carbon into and out of a given ecosystem. Measurement of stocks at the beginning of 2008 and at the end of 2012 (or at the date of commencement of the relevant activity between 2008 and 2012) will yield the change in stocks that has occurred over the first commitment period. Alternatively, measuring the flux of carbon into or out of an ecosystem over the five-year period will also yield the net change. One method can be used to measure losses or accumulations of carbon on land while another, independent method is needed to verify the change. The whole suite of available measurement methods for monitoring and verification is given in Box 1. They allow consistent monitoring and verification from plot scale to regional, national and continental scale. Whilst the technology has been readily developed, the application and coupling to models is still in a research phase and associated with considerable uncertainty, especially the flux measurements, remote sensing and models. However, if present activities continue at constant pace, a more operational verification system will probably be in place by 2012.

Table 6 Monitoring, verifiability and transparency of potential Article 3.4 activities in the agricultural sector (Smith 2001)

Article 3.4 Activity	Monitoring, verifiability and transparency
1) Cropland management to provide higher carbon inputs to the soil	The change in soil carbon can be verified through ground-truthing (on-site sampling) and well calibrated models. Periodic monitoring using benchmark sites – measure bulk density and soil organic carbon content to 1m every 5-10 years. Small depth increments. Most sampling is limited to 0-30 cm.
2) Irrigation water management	See 1, plus: area irrigated by remote sensing.
3) Conservation tillage	See 1, plus: soil sampling and measurement of residue return for a few sites. Ground survey and possibly remote sensing to assess area & residue coverage.
4) Erosion-control practices	See 1, plus: terraces, waterways etc are conspicuous and easily verified via remote sensing and ground-truthing.
5) Management of rice cultivation	See 1, plus: measurement of methane fluxes is technically challenging and expensive – methane fluxes variable in space and time – models may be of use.
6) Grazing management	Rates of change from repeated field experiments (soil and vegetation) over time, for representative grassland types and grazing regimes. Models may help. Conventional vegetation mapping and remote sensing can be used to determine geographic extent of grazing lands. Rough estimates of past and current grazing intensity from animal stocking rate surveys.
7) Protected grassland and set-aside	No details given
8) Grassland productivity improvements	Repeat direct sampling of soils and vegetation. Could be scaled up. May also need statistics on area of improved pasture, fertilisation rates, and livestock density and characteristics.
9) Fire management in grasslands	Changes by repeat sampling in a monitoring network. At plot level allometry and stem growth increment can be used. Verification and auditing by satellite imagery to confirm integrity of registered sites and auditing undertaken on a subset of these sites.

Source: Compiled from IPCC, Special Report on Land Use, Land-Use Change and Forestry (SR-LULUCF), Cambridge University Press, Cambridge, 2000, pp. 249-279.

Soil carbon stock changes are best measured by pair-wise point time-series, e.g. in 5-year intervals, i.e. by resampling soil as close as possible to the preceding sampling. This requires high precision GPS- and GIS-based sampling but avoids the plot scale spatial heterogeneity in the traditional statistical soil sampling schemes. The number of samples can be probably reduced as compared to the first carbon inventory. Highly accurate geo-referencing of sampling spots is crucial for further monitoring of carbon stock changes by periodic resampling at the same location for the monitoring of carbon stock changes. In analogy with the monitoring scheme of ICP Forests, two intensity levels for soil sampling are suggested.

Many, regularly distributed plots: Core parameters, i.e. soil type, soil moisture regime, total carbon contents, organic carbon content, total nitrogen content, bulk density, stone content.

Benchmark plots: Core parameters plus indicators of easily degradable soil organic matter such as litter (mean residence time: months to year), light fraction carbon, or particulate organic matter inside and outside macroaggregates (years to decades), an indicator of biological activity like microbial biomass, soil enzymes, or soil respiration, as well as stable humus and charcoal (>centuries). These plots serve as early indicators for carbon stock changes and for model parameterisation.

The point measurements are upscaled by GIS-based modelling including information derived from a soil map, climate parameters, digital elevation model, and remote sensing products for land cover and soil moisture, if possible.

Alternatively, with statistical sampling, the number of samples must be increased depending on the spatial coefficient of variation until temporal differences are detected with the desired uncertainty. As illustrated by Post et al. (2001) and Watson et al. (2000), in order to detect a typical carbon sequestration of 1.5 t C over a five-years commitment period at $p < 0.05$ with 90 % confidence, 32 samples are needed at a spatial variability of 20 %, but more than 250 if the spatial variability increases to 58 % - a still moderate range. Alternatively, the uncertainty in the stock change estimate increases. Consequently, economic constraints will make carbon stock changes undetectable over a five-years period with a statistical sampling scheme.

Data availability and data quality

What data and information is actually needed depends on the desired stringency of verification. In order to account for the effects of land management, also relevant information about C and N input and cycling and management practice is required.

Carbon and nitrogen in biomass (annually): carbon and nitrogen in harvested products, residues and roots, including intercrops, feed and grazed biomass. Data could be provided directly by farmers through the extension of nutrient balance reporting at field level resolution.

Land management: Crop rotations including intercrops, yields, organic residues, amount and distribution organic amendments, tillage practice, fertilisation, to be potentially provided by farmers at field level resolution.

Measured soil carbon stock changes are scaled to the area identified for Article 3.4 activities using soil carbon models on a GIS basis, as this was demonstrated with respect to baseline organic carbon (Rusco et al., 2003). Since each of the available models has its particular advantages and drawbacks and relies on hardly verifiable assumptions, it is recommended to rely on a set of models rather than on a single one.

The attraction of flux methods is that they are entirely independent of stock change methods to check stock change results. The IPCC report notes, however, that flux measurement methods are not yet sufficiently reliable to be used as the primary method of measuring losses or accumulations of carbon on land, and as such are of limited use at present as a verification method. Further, because the whole ecosystem exchange is measured, it is difficult to factor out the different contributions of soil, roots and above ground vegetation. Flux measurement equipment is expensive and does not exist for most sites.

Harmonisation of sampling schemes (stratification, statistical design, sampling depth intervals), sample processing (separation of coarse root fragments, drying, sieving, etc.) and analyses as well as of data and sample archiving is recommended. The European Topic Centre on Soils is working on a strategy for soil quality and soil monitoring (Huber et al. 2001), including carbon stocks and organic matter. We suggest linking these as well as other ongoing national activities with monitoring for the Kyoto Protocol. According to Huber et al. (2001), total soil organic carbon already belongs to the core parameters covered in soil surveys, but in many cases, only topsoil organic carbon has been determined. Bulk density and stone content are underrepresented in existing soil databases as are indicators of biological activity and easily degradable soil organic matter. Huber et al. (2001) also highlight the importance of monitoring carbon in peatlands, but other greenhouse gases are equally important in these areas.

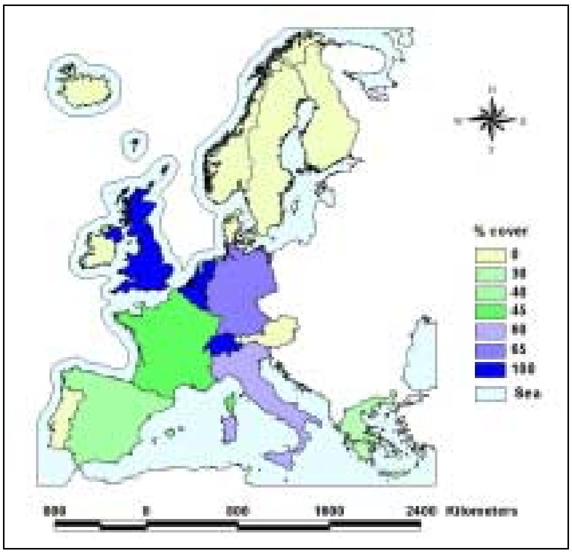


Figure 9: Availability of 1:250,000 scale soil surveys in the EU and EFTA countries

Data availability problems stem mainly from inadequate soil maps (Bullock 1999) that are regionally incomplete (see Figure 9). This is the result of severe cutbacks in soil survey activity as a direct result of agricultural surpluses generated in Europe in the early 1980s. In parallel, information about agricultural management is also inadequate. In terms of ecosystem productivity and crop yields regional differences do exist and are important; the FAO data set however contains country specific data without any sub country specific information. For grassland production only a limited amount of data is available adding to the large uncertainty associated with the spatial variability.

Management practices also vary from place to place; most important for carbon sequestration are soil management/tillage, the use of organic manure and sewage sludge. At a European scale no information is available on regional preferences.

It is worth noting that the data used in the studies quoted here are based on statistics provided by the FAO, at the national scale for Europe. It would have been preferable to use the Eurostat sources of data, but these tend to be patchy in terms of regional and temporal coverage. Whilst, for example, the REGIO database is able to provide statistics on the basis of NUTS2 regions, there are many missing data, which limit the usefulness of the statistics.

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. This view was supported in the Council conclusions on integrated soil protection (10800/02). The proposal provides for a soil monitoring legislation, making use of existing information systems, databases and know-how, in so far as possible.

Attribution

The attribution of carbon sequestration and a reduction of soil borne greenhouse gas emissions is best monitored with control plots under „business as usual" land management, which also serve as a reference for climate-driven interannual variability.

Net greenhouse gas fluxes in the base year 1990

Net greenhouse gas fluxes in the base year 1990 can only be modelled retrospectively, best using several soil carbon models in a GIS framework. Obligatory model inputs are 1) climatic variables (temperature, precipitation, for some models radiation) at best temporal and spatial resolution, 2) soil map, 3) land use and land management history for at least 20-50 years at highest possible spatial resolution, and 4) land management in 1990, including tillage practice, crop rotations, yields and input of organic amendments and residues.

Control of implementation of Article 3.4 activities

Carbon sequestration in agricultural soils only works if the activities are adopted at a continuous, contiguous basis. Once a conservation tillage system is interrupted by mouldboard ploughing, or a rewetted peatland is re-drained, the carbon sequestered over a period of several years is released again within a short period. In order to make carbon sequestration activities permanent, political incentives and stringent control are required. Apart from ground surveys, remote-sensing products will help in the future to monitor water management in rewetted peatlands and conservation tillage if minimum residue coverage of the soil is prescribed.

4.3 Verification across scales

Monitoring and verification are best embedded in a broader scheme including all types of land use and land use change and all greenhouse gases. Verification of carbon sinks and changes in soil borne greenhouse gas emissions best relies on a multiple constraint system that allows the verification at project, regional (county), national and European level (Box 1).

Box 1: Measurement methods for assessing losses or accumulations of carbon on land (Smith 2001)

Measurement methods for assessing losses or accumulations of carbon on land

Stock change measurements methods

- Vegetation inventory
  - Stemwood volume – forest inventory
  - Total tree biomass – allometry
- Wood products – models of wood products
- Soil and litter
  - Woody debris – volume and mass measured
  - Litter – sampling and carbon analysis – highly spatially variable
  - Mineral soil – sampling and carbon analysis – highly spatially variable

  (*Sampling strategy, methods and sampling depth all need to be considered*)

Flux measurement methods

- Chambers, Eddy covariance – for scales less 1 km^2
- Tall towers, balloons for convective boundary layer budgeting – Landscape, regional scale
- Flask measurements and flux measurements from aircraft; coupled with inversion analysis – continental scale.

Remote sensing to determine geographic extent and change

- Current resolution (NOAA-AVHRR) is 1 km^2 but 30m possible soon
- Geographic extent possible, vegetation type possible, residue over, tillage, and perhaps soil organic carbon and moisture content of bare soil will become possible in near future

Models

- To be used in combination with the above methods
- To assimilate observational data in a future operational mode

Again, complementary observation methods are combined with a suite of models. At the project scale, a probably small number of intensive monitoring sites should be established at which continuous measurements of soil and ecosystem carbon fluxes (also continuous soil respiration measurements in order to partition the ecosystem fluxes between above ground biomass and soil), soil moisture and temperature and regular analysis of biomass stocks, carbon and nitrogen fluxes (harvest, residues, litter, roots,…) and soil carbon and nitrogen stocks in addition to Level II parameters are performed. The models used for monitoring are verified against these measurements. Eddy covariance (CO_2, CH_4) and relaxed eddy accumulation (N_2O) methods on small (5-40 m) and tall (> 100 m) towers serve to verify the carbon and greenhouse gas budgets at ecosystem and regional scale. At the national to continental scale, the total CO_2 and CH_4 budget, but not the attribution to Article 3.4 activities, can be verified by measurements of atmospheric concentrations of trace gases and isotopes in conjunction with inverse atmospheric models.

The fate of laterally transported carbon and nitrogen through erosion and leaching needs to be considered.

5 The Contribution of European Policy Instruments to the Sequestration Potential of Agricultural Soils

5.1 Introduction

This chapter has three principal aims: to review the Common Agricultural Policy (CAP) measures since 1990, to estimate the potential effects of these measures on soil carbon sequestration, and finally, to assess how policy and land management may have affected farm incomes in Europe. The chapter focuses primarily on European policy rather than national level policy, and includes an assessment of both production-related measures as well as rural development and agri-environment policies. Whilst there are some clear relationships between land use and CAP policy, in general, it can be very difficult to disaggregate from direct policy effects the influence of a multitude of socio-economic trends on the agricultural sector. Some discussion is included, therefore, of the role of these other effects where known.

The 1990s experienced radical change in the structure of the CAP with a move away from price support based on production to area-based payments, and the introduction of a wealth of agri-environmental policies. These all have the potential to affect land use and management and, therefore, soil carbon sequestration. The question this chapter seeks to address is, what is the magnitude of these effects?

5.2 Brief review of European policies post-1990

5.2.1 Sectoral production policies

MacSharry reforms (1992)

Whilst the Treaty of Rome (1957) conceived the CAP as having multiple objectives[2], one objective - maintaining producer prices through market intervention - came to dominant the policy mechanisms. Following subsequent production surpluses, EU budget crises and international trade agreement pressures, it became clear that a radical reform of the CAP was required. The 1992 MacSharry reforms sought to tackle these problems by lowering intervention prices, and replacing the resulting losses of farm income by direct area-based payments linked to production controls based on set aside. At the same time, a range of further policies was introduced that addressed environmental protection, rural development and structural reform. The 1992 reforms were further modified more recently (in regulations dated 1999) within the framework of Agenda 2000.

Arable area payments and set aside. An important component of the 1992 reforms were to change support mechanisms for arable crops from production based price intervention, to direct aid based on the area of crop production. The area payments were conditional on a certain proportion of land on each farm being set aside to reduce total production. The original 1992 set aside requirement was fixed at 15%, but this has changed over the years reducing to 5% in 1996/97, but returning to 10% at present. The original intention was for set aside land to be part of a rotation (to avoid the least productive land being set aside, and therefore affecting the aim of reducing production). From 1994, however, a non-rotational form of set-aside (for a minimum of 5 years) was made available to farmers based on an additional 5% of land above the rotational requirement. More recently, the distinction between rotational and non-rotational set aside has been abolished, being replaced with 'obligatory' set aside that can be for a fixed location, or moved between fields each year. In addition to the basic obligation, voluntary set aside is also possible on land up to the maximum cropped area for which payments are being claimed. Currently, set aside land can also be used for tree planting and non-food crops such as biofuels. This may, however, be changed in the future, according to the Commission's CAP reform proposal (COM (2003) 23 final).

Livestock. Prior to 1992, the livestock policies of the CAP had, as for arable crops, encouraged increased production resulting in greater animal numbers. The MacSharry reforms sought to tackle this problem by reducing the intervention price for beef by 15%. As a result, premiums for cattle were increased to compensate for loss of income, provided farmers reduced stocking densities from 3.5 to 2 LU/ha from 1996 onwards. Additional payments were available for reductions to 1.4 LU/ha. On the whole, these measures encouraged extensive livestock production. The exception was in regions where extensive grazing was previously the norm and traditional stocking densities were already < 1 LU/ha, e.g. the Dehesa and Montado land use systems of Spain and Portugal. In these cases, stocking densities actually increased.

The 1992 reform also sought to reduce sheep numbers by imposing limits per flock of the number of ewes qualifying for premiums, with a quota on direct payments. Furthermore, in an attempt to maintain or restore grazing on upland pastures that might otherwise have been abandoned, premiums were limited to 1000 ewes in LFAs, but 500 elsewhere.

Olive production. Olive plantation areas have fluctuated considerably over recent decades, following different national and regional policies. A general decline in olive areas, however, occurred during the 1970s and 1980s due to a combination of abandonment and restructuring programmes (grants for grubbing-out old trees). In the 1980s and 1990s, there was a strong

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[2] Increasing agricultural productivity through technical progress and rational development, ensuring a fair standard of living for the agricultural community, stabilising markets, assuring the availability of supplies at reasonable consumer prices.

expansion of new plantations, especially in regions with a comparative advantage (notably Spain and Greece, but to a lesser extent Italy and Portugal), and an intensification of production practices.

Wine sector. The area of vineyards has declined substantially between 1980 and 1995, which was also reflected in the overall production of wine. The loss of vineyards was strongly influenced by the Community aid for the grubbing-up of vines, and a shift either to better quality wine production or the cultivation of other crops.

Agenda 2000 reforms

The 1992 reforms were further modified at the end of the 90s within the framework of Agenda 2000. Regulation 1259/99 established common rules for direct support schemes within the CAP to be implemented from the 2000/2001 marketing year onwards. For arable crops specific new regulations included 1251/99 establishing a support system for producers of certain arable crops (replacing regulation 1765/92), 1252/99 establishing a quota system for the production of potato starch (replacing Regulation 1868/94), and 1253/99 fixing standard qualities for cereals. These regulations included a number of measures:

- Cereal intervention prices were reduced (by 15%) and direct area payments increased from 54 to 63 €/t (representing 50% of the overall price cut);
- Grass silage (where maize is not cultivated) became eligible for arable crops area payments;
- Oilseed and linseed direct payments per year will be reduced in line with cereal payments;
- Protein crops will receive a premium payment on top of the basic direct payment (to ensure their profitability);
- Set-aside compensation (compulsory and voluntary) is established at the same rate as for arable crops (i.e. 63 €/t). The basic compulsory rate is set at 10% (until 2006/07), but small producers (< 92 t) are still exempt;
- The minimum price for potato starch is cut by 15% with increases in the aid payment equivalent to 75% of the intervention price cut). Lower production quotas are also enforced.

For the meat sector (as well as specific livestock regulations), special ‘extensification’ premiums will be paid for stocking densities of < 1.4 LU/ha. This is intended to avoid the problem of increasing stocking densities on already extensive land that was a consequence of the MacSharry reforms. For the dairy sector (Regulation 1255/99) intervention prices for butter and milk powder were reduced being offset by the introduction of direct aid payments. Quotas were maintained. Regulations were also introduced for the wine sector (1493/99), olive oil and tobacco.

5.2.2 Past reforms concerning rural development and environmental policies

Rural development

Present EU rural development structural policies dates back to the 1988 reforms of the Structural Funds, which introduced regional and horizontal Objectives. The regional Objectives of relevance to rural development included:

- Objective 1 regions that lag behind economically (GDP < 75% of the EU average)
- Objective 5a, horizontal measures to speed up the adjustment of agricultural structures
- Objective 5b, rural areas with low levels of development and high dependency on agriculture
- Objective 6, regions (north of Lat 62) with very low population densities (< 8 inhabitants per km²).

These Objectives covered nearly 75% of the EU's area and nearly 35% of the population. Rural development policies were extended through Regulation 1257/99, which concerned support for rural development by the European Agricultural Guidance and Guarantee Fund (EAGGF). This regulation established rural development policy as the "second pillar" of the CAP, and introduced an Objective 2, rural areas (formerly Objectives 5a and 5b). Rural development measures for 2000-2006 extend previous policies by focusing on farm structure measures and 4 *accompanying measures*:

- compensatory payments for less favoured areas (LFAs) and for areas with environmental restrictions due to Community environmental protection rules,
- forestation of agricultural areas,
- agri-environment, and
- early retirement.

These policies were firmly based on previous measures, and are discussed further below.

Less Favoured Areas

The introduction of direct aid and specific measures for Less Favoured Areas (LFAs) was proposed as a means of enabling farming to continue in areas where production conditions were more difficult. Its goals were a combination of economic, social and environmental. Directive 75/268 (which later formed part of Regulation 950/97, and which is now integrated into Regulation 1257/99) defined the concept, classification and compensation criteria of LFAs, establishing three distinct types:

- *Mountain and hill areas* (about 20% of the UAA), where altitude and slopes reduce the growing season and the scope of mechanisation;
- *'Simple' LFAs* (34% of the UAA), marked by poor soils, low agricultural incomes and low population density or population density in decline for agricultural reasons;

- *'Specific handicap' LFAs* (2% of the UAA), small areas with poor water supplies, periodic flooding, etc. where agricultural activity should be continued in order to maintain the countryside and preserve the environment.

LFAs, as classified by Member States, benefit directly from specific measures set out in Regulation 2328/91: compensatory allowances per animal and/or per hectare and investment aid for farm modernisation or grazing improvement (for a minimum of 3 years on farms of at least 3 ha). They also benefit indirectly from the favourable implementation of other measures (e.g. top-ups on sheep premiums or additional quotas) and the greater impact that other measures have in LFAs (e.g. agri-environmental measures and direct aid for extensive farming and for improving the efficiency of agricultural structures).

The proportion of the European UAA, classified as LFAs grew from 36% in 1975 to 55% in 1995, the areas varying considerably between member states (0% in Denmark, where the scheme is not yet applied and 98% in Luxembourg). The LFAs (at 55% of the UAA) include nearly one third of the cattle and dairy production and two thirds of the sheep in the EU (European Commission, 1997)

Forestation of agricultural land

There is no common forestry policy, but a number of measures that affect the forestry sector and agricultural land. Regulation 1610/89, provided measures to promote forests in rural and less developed regions, with priority given to areas where forestry can help the economy, create jobs, encourage tourism and recreation, tackle erosion or protect soil and water resources.

The *Community aid scheme for forestry measures in agriculture* (2080/92) aimed both to control agricultural production and contribute to long-term forest resources (including environmental benefits such as CO_2 absorption). Financial aid is given (on a contractual basis) to cover the costs of afforestation, forest maintenance, income loss and investment to improve existing farm woodland (e.g. to reduce fire loss under Regulation 2158/92). The measures were expected to generate 700,000 ha of forests by 1997 and to contribute to the improvement of about 300,000 ha of existing woodland.

Agri-environmental measures

Regulation 2078/92 (Agri-environmental measures) was a general framework that was implemented by member states through zonal programmes. Premiums were paid to farmers (based on loss of income) on a voluntary and contractual basis (minimum 5 years) for a number of different actions, including:

- Reducing the use of fertilisers and plant protection products or developing organic farming production methods;
- Changing to or maintaining extensive crop production, or converting arable land to extensive grassland;

- Reducing stocking rates (per ha) of sheep and cattle;
- Using farming practices that are compatible with the protection of the environment, countryside and landscapes;
- Maintaining abandoned agricultural land or woodlands for environmental protection;
- Establishing reserves, natural parks or hydrological protection systems by setting aside land for at least 20 years;
- Managing land for public access and leisure activities.

Implementation of the regulation was completed by the end of the 95/96 growing season. Zonal programmes were designed taking into account the agricultural and rural characteristics of the area (abandonment, pollution, biodiversity), the impact of the programme on the environment, and contributions to the reduction in production and market imbalances. Environmental priorities and implementation methods varied considerably between member states.

The organic production of agricultural products is regulated by Regulation 2092/91. This sets out strict requirements which must be met before agricultural products (whether produced within or outside of the EU) may be marketed as organic. The agri-environmental measures in Regulation 2078/92 encouraged conversion to, and maintenance of, organic farming by providing financial compensation to farmers for losses incurred during conversion plus additional financial incentives.

Farm structure reform

There is a long history during the evolution of the CAP of the need to reform the structure of farms and farming in the EU, dating back to the 'Mansholt Memorandum' in 1968. These policies have the potential to modify land use and management decision making, although in practice quantifying their effects is difficult. Recent policy has sought to modernise agricultural holdings (Regulation 950/97, and formerly 2328/91) through aid for agricultural investment, education and early retirement, and improve processing and marketing of agricultural and forestry products including the creation of producer groups (regulations 951/97, formerly 866/90, 867/90, 952/97, formerly 1360/78).

Nitrates Directive (91/676)

The Nitrates Directive aims to reduce water pollution caused or induced by nitrates from agricultural sources and to prevent further such pollution. The Directive requires Member States to establish 'codes of good agricultural practice', to designate 'nitrate vulnerable zones' based on monitoring of the level of nitrates in water including trends and on the presence of eutrophication and to establish action programmes in such zones.

While the codes of good agricultural practice are voluntary outside vulnerable zones, the action programmes within the Nitrate Vulnerable Zones (NVZs) incorporate the codes, are obligatory and include a number of additional compulsory measures such as:

- Bans on the use of fertilisers during certain periods;
- Limits on fertiliser applications (as a function of the characteristics of the NVZ);
- Limits on the application of livestock manure (no more than 170 kg N / ha);
- Conditions determining the amount of on-farm storage for livestock manure.

Some countries (Germany, Austria, Finland, Denmark, the Netherlands and Luxembourg) have designated their entire land areas as a NVZ, while all others (except Ireland to date) have designated at least part of their territories as nitrate vulnerable. Action programmes have been established for these zones but it is anticipated that there will be further designation in coming years together with an extension of the action programmes.

Other policies

In 2002, the Commission published a communication "Towards a thematic Strategy for soil protection" which deals inter alia with the functions and policy features of soil and with the threats facing it. It indicated eight major threats, which could undermine its ability to carry out its functions, including a decline in organic matter, erosion, contamination and sealing. In addition to addressing the monitoring question (see Chapter 4.2) it also set down a vision for soil protection for sustainable use in the future and indicated its intention regarding action to achieve this in coming years. An important aspect of this approach will be a further Communication foreseen for 2004 dealing with organic matter, erosion and contamination and a proposal for soil monitoring which should be of particular interest for establishing soil organic matter levels.

5.3 Other socio-economic (non-CAP) drivers of land use change

Whilst in principle the CAP has appropriate mechanisms to modify land use change in Europe, we must also recognise that there are several other socio-economic drivers that can play an important role. These include:

- Technological change (e.g. plant and animal breeding);
- World markets, and international trade agreements;
- Social change (e.g. hobby farms, part-time farming);
- Changing consumer trends – less meat, shifts from olive to sunflower oil, etc.;
- Opportunity costs of labour, i.e. the effect of regional economic development and disparities (encouraging less labour intensive land uses);
- Land degradation (e.g. erosion);
- Irrigation water availability and quality;
- Improved farmer education and information dissemination e.g. Hägerstrand (1968) showed the importance of diffusion of information in determining land management practices.

5.4 Land use and management change arising from European Policy

5.4.1 General effects

The CAP has an impact on land use and management through its Common Market Organisations (CMOs) for each commodity as well as through the rural development measures (agri-environmental measures and LFAs). CMO mechanisms can be divided into (Oppenheimer, Wolff & Donnelly, 1997):

- Market support (intervention, import duties) to maintain producer prices;
- Production control (quotas or set aside) and,
- Direct aid (arable area payments).

One of the aims of the CAP mechanisms has been to maintain farm incomes by means of price policy. This affects land use because, put simply, higher prices for a crop (relative to other crops) increases profitability resulting in more of that crop being grown. Measures targeted to regulate production, such as set aside, have a clear direct impact on land use, specifying minimum areas of a non (or non-food) use. The effects of arable area payments are less clear, although one could argue that removing the link to production (as was current before 1992), could maintain arable production in marginal arable areas that would not otherwise be able to compete at world price levels.

Agri-environmental measures may affect farmer land use practices through their influence on profitability. LFA regulations generally favour land uses (such as extensive grazing) that would not normally be possible because they are not economically viable.

The original CAP market mechanisms were based on production-related price support, which led to over supply of many foodstuffs. Farmers sought to raise yields by increasing the use of fertilisers and pesticides and higher stocking densities (Mortimer, 1998). This process of increasing production inputs is known as *intensification*. The CAP has also encouraged *specialisation* of particular crops (e.g. cereals, oilseeds and peas/beans) and livestock enterprises (e.g. dairy) through high levels of subsidy where favourable growing conditions exist. Such changes have encouraged monocultures with the loss of mixed farming enterprises. Specialisation has both impacts on land use, landscape character and biodiversity in these areas. In southern member states there has been a decline in the productive use of large areas of agricultural land of poor quality, mainly under mixed and low productivity livestock systems. The low returns from these enterprises have required farmers to seek alternative sources of income or to intensify production methods. These changes have led to the social and economic *marginalisation* of farming. In more extreme cases, poor infrastructure provision, low economic vitality, declining populations and low agricultural productivity have seen the *abandonment* of farmed land.

The following section discusses some specific changes in land use and management activities that can reasonably be assumed to have a link with policy. Where it is difficult to disaggregate the effects of other trends (e.g. macroeconomics, international trade agreements, technological development), these are also discussed.

5.4.2 Changes in specific land uses

The agricultural area

The total agricultural area in the EU15 has decreased considerably since the early 1960s (by more than 10 % according to FAO data). This is an important point to note because changes in the areas of specific cops should be set against the overall decline in agricultural areas. Thus, a lower production of some crops could be explained by this decline, but production increases for other crops could have been even greater if it were not for the loss of agricultural land. The overall loss of agricultural land can probably be explained by conversions to woodland, amenity land uses and abandonment. Note that the decline in agricultural areas has been especially rapid since 1990 (Figure 1Figure 10).

Set aside

Compulsory set aside is one of the few land use changes that can unequivocally be stated as being directly and solely a consequence of the CAP following the 1992 MacSharry reforms. Table 7 shows the land areas that were affected by set aside in the 1994/95, 1998/99 and 1999/00 growing seasons. The set aside areas change from year to year because of changes in the terms of the policy regulations. The current policy requires 10 % set aside with a provision for voluntary set aside up to a maximum of 50 % of the arable area.

Table 7 Areas of set aside (1000 ha) in the EU member states (source: European Commission, 2001)

	1994/95					1998/99		1999/00	
	Total area	**Rotat-ional**	**Non-rotat-ional**	**Volun-tary**	**Old scheme (5yr)**	**Total area**	**Indust-rial***	**Total area**	**Indust-rial***
Belgique & Luxembourg	29	22	5	1	1	14.2	2.3	24.3	5
Danmark	271	119	147	N/A	6	153.5	10.6	211	27
Deutschland	1616	692	703	N/A	221	806.6	147.7	1175	362
Elláda	18	18	0	0	0	13.2	0	25	0
Espaňa	1417	996	66	287	68	1308.7	18.8	1343	41
France	2123	1068	767	98	190	938.2	224.9	1471	423
Ireland	36	38	-	-	0	20.2	0.5	30	0
Italia	961	210	40	N/A	711	157.9	14.3	234	27
Nederland	28	12	2	N/A	14	6.4	0.2	17	0
Österreich	-	-	-	-	-	71.4	3.7	106	10
Portugal	67	67	-	N/A	0	71.6	-	55	0
Suomi/ Finland	-	-	-	-	-	155.9	0.3	201	1
Sverige	-	-	-	-	-	1941	17.5	271	19
United Kingdom	741	497	158	N/A	86	295.2	30	578	119
EU12	7307	3737	1674	600	1296	-	-	-	-
EU15	-	-	-	-	-	4207	470.7	5741.3	1034

*Note: industrial set-aside (Regulations 1765/92 and 224/93) includes non-food crops grown on set-aside land and is a part, therefore, of the total area

From the perspective of carbon, set aside is interesting because of the potential for carbon sequestration in soils and for fossil fuel off-set using biofuels planted on set aside land. Current estimates suggest that 20 % of set aside land is being used for non-food crops, of which rapeseed for the production of biodiesel accounts for 80 % (Joaris, 2002) (see Table 8). This has probably also contributed to the continued expansion of oilseed rape during the 1990s.

It should be noted that the CAP reform proposal from the Commission (COM (2003) 23 final) does not foresee the possibility to continue non-food production on set aside land.

Table 8 Development of Renewable Energy Sources (RES) on set aside land in the EU (1000 ha) (after Joaris, 2002)

	1993	1994	1995	1996	1997	1998
Total non-food set aside	242	707	1045	718	451	467
Of which crops for liquid bio-fuels	236	698	1021	690	423	438
Of which crops for direct combustion	1	1	14	18	18	19

Grassland

There has been a clear decline in the area of grassland in Europe during the period of the CAP (see Figure 10). This can primarily be attributed to the increased production of maize (see above), especially in more intensive (i.e. lowland) livestock areas, at a time when livestock numbers were reducing due to the implementation of milk quotas in 1984. Since the early 1990s, however, the grassland areas have been relatively stable. This can probably be attributed to two effects: the 1992 CAP price support reforms and the introduction of agri-environmental and rural development reforms. The MacSharry reforms may have contributed to prevent any further grassland to arable conversions, by fixing the area of land that was eligible for arable area payments. Thus, only land that was in arable production on 31 December 1991 could claim the aid payment.

The LFA policies have probably contributed to the maintenance of permanent pastures in arid and upland grazing areas. Thus, as the LFA policy has effectively maintained the *status quo* in terms of grassland areas, from a carbon sequestration potential point of view, one could question what land use would have existed if marginal areas were abandoned or converted to other uses. Would, for example, the return of natural vegetation types have led to an increase in carbon sequestration? This might be especially important in upland areas that would tend to acidification. This effect, however, is currently not quantifiable.

It is worth noting that the data used in this report are based on statistics provided by the FAO, at the national scale for Europe. It would have been preferable to use the Eurostat sources of data, but these tend to be patchy in terms of regional and temporal coverage. Whilst, for example, the REGIO database is able to provide statistics on the basis of NUTS2 regions, there are many missing data, which limit the usefulness of the statistics.

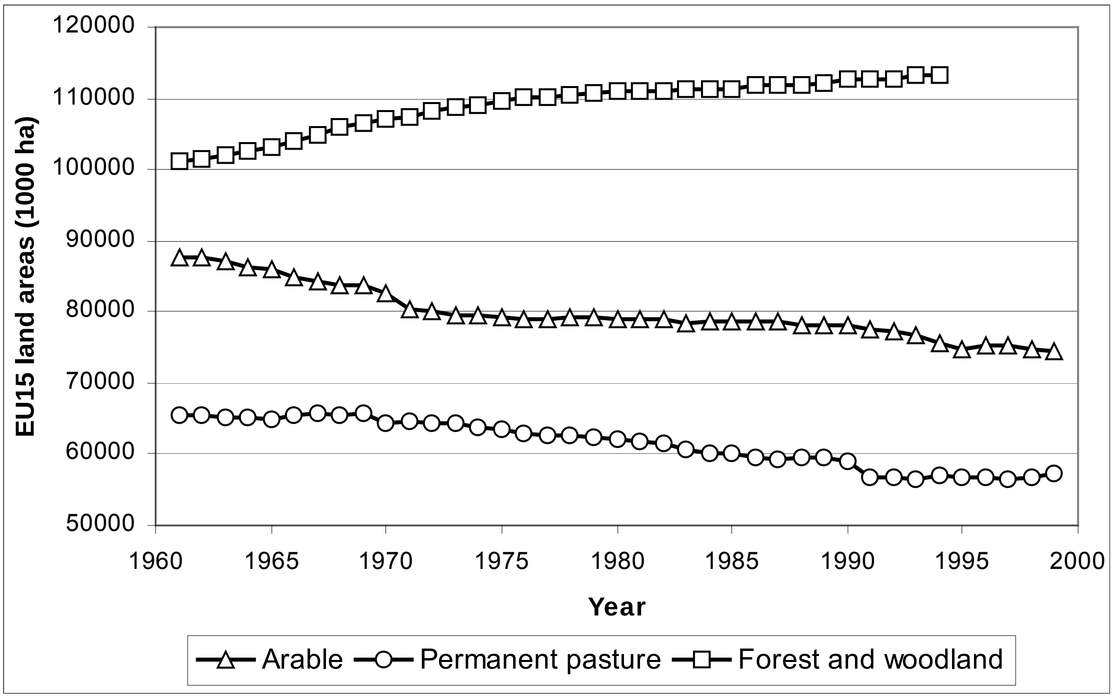

Figure 10 The change in area of arable crops, permanent pasture and woodland in the EU15 (source, FAO: www.fao.org)

Forestation of agricultural land

The total area of forests and woodland in Europe has increased consistently throughout the period of the CAP (see Figure 10). Whilst there are some doubts about the reliability of some of these data during the 1970s (Nucifora, 2001), the general increasing trend is clear. Whilst woodland on agricultural land only accounts for a small proportion of the total, the recent afforestation policies have clearly contributed to these increases. A total of 519,350 ha (excluding Belgium and Sweden) were afforested under regulation 2080/92 between 1993 and 1997 with Spain alone accounting for 46% of this area. Of this total forested area, two-thirds are located in areas classed as presenting a fire risk under regulation 2158/92. For the EU15 as a whole, the breakdown of land use change was: 60% from permanent pasture and meadow, 37% from arable land and 3% from permanent crops. The types of trees planted are 40% conifers, and 60% broadleaf, mixed plantations (> 75% broadleaf) and fast-growing plantations, for the EU15 as a whole. For individual countries, however, the breakdown of tree types varies greatly, e.g. Ireland has > 80% conifers, but all other countries have < 50% conifers.

Organic farming

The total area of land devoted to organic farming is just under 2% of the UAA of the EU15, but varies considerably between countries. Italy alone has 27% of the EU organic land, followed by Germany (16%) Austria (12%) and Sweden (9%).

Nitrate Vulnerable Zones

It is difficult to quantify if the Nitrates Directive has influenced land use. In theory, the policy might influence the relative profitability between farm enterprises and, therefore, farmer land use decisions. The vulnerable zones, however, vary between different regions of Europe, (some located in areas of intensive livestock production and others in areas of intensive arable production) so that at the European scale it does not seem possible to draw firm conclusions about actual land use change.

There is a further potential influence of nitrogen controls on carbon sequestration. The addition of N fertiliser may play a role in soil carbon contents, so that limits on N additions by farmers could reduce the quantity of soil carbon. It is, however, very difficult to quantify this effect and it should be emphasised that the levels of N which cause nitrate problems for water are already very high (often greater than 250 kg N/ha). So it is doubtful if limiting N use plays any role in preventing carbon build up.

A more direct effect of the Nitrates Directive on GHG mitigation is expected from a more rational use of fertiliser. A reduction of excess N use will certainly contribute to a reduction in N_2O emissions, so bringing greenhouse gas benefits.

Permanent crops

The area of permanent crops has reduced substantially since the mid 1970s (see Figure 11). This was mostly attributable to the reduction in the area of vineyards between 1980 and 1995, which was also reflected in a decline in the overall production of wine. The loss of vineyards was strongly influenced by the Community aid for the grubbing-up of vines, and a shift either to better quality wine production or the cultivation of other crops. Olive plantation areas have tended to remain fairly stable during this period, although there has been a trend of replacing older systems with more up-to-date production methods. However, this has lead to increasing concerns about soil erosion.

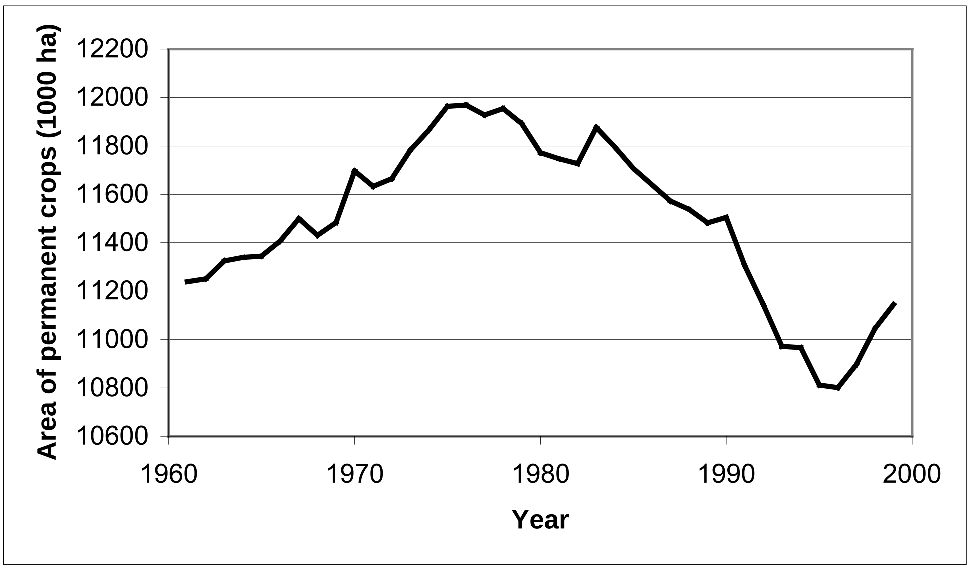

Figure 11 The area of permanent crops (vineyards, olives, orchards) in the EU15 (source, FAO: www.fao.org)

5.5 Effects on farm incomes

5.5.1 Effect of policy on farm incomes

Since the Treaty of Rome, one of the underlying principles of the CAP has been to maintain farmer incomes. This principle has continued into the 1990s, and each new policy whether related to production, rural development or agri-environment has had some mechanism for compensating farmers for potential losses in income following the implementation of the policy. AGENDA 2000, for example, has been estimated to have increased average farm incomes by 4.5 % (Mortimer, 1998). Furthermore, policies such as the LFAs have as their main aim the maintenance of incomes in disadvantaged areas, i.e. where farming would otherwise not be viable. There are, however, regional disparities in these effects with northern European countries (except Ireland) benefiting from higher LFA subsidy payments than in the south. Some incomes in simple LFAs in France and Germany, for example, are even higher than the EU average. Thus, in general the effect of post 1990 policies on farmer incomes has been positive or at worst neutral.

5.5.2 Factors affecting farm profitability of soil carbon sequestration measures

In addition to the effect of specific CAP policies on farmer incomes, one can also examine the potential effects of soil carbon sequestration measures based on land management. It is, however, very difficult to assess the impact of these measures on farm profitability and/or costs, although it is possible to describe these effects qualitatively. Some potential impacts are described in Table 9.

Table 9 Factors affecting farm profitability of soil carbon sequestration measures

Measure	Potential positive effects on farm profitability	Potential negative effects on farm profitability	Overall effect on farm profitability
Crop-land			
Zero-tillage	In dry areas may improve productivity via improved moisture retention. Work time and fuel consumption decreases, less powerful tractors needed.	In wetter areas more risk of fungal attack, reduced emergence and crop failure. High initial equipment investment cost.	+ or – unclear, regionally specific
Reduced-tillage	In dry areas may improve productivity via improved moisture retention	In wetter areas more risk of fungal attack, reduced emergence and crop failure.	+ or – unclear, regionally specific
Set-aside	Possible better long term soil fertility	Unless subsidised, reduced area available for production	+ or -
Perennial grasses and permanent crops	Possible better long term soil fertility	Less flexibility to respond to market changes	+ or -
Deep-rooting crops	Possible better long term soil fertility	Potential costs due to changes in cultivation techniques.	+ or -
Animal manure	Possible better long term	Higher transport costs.	Depends on

	soil fertility		local/regional proximity of livestock and arable production. Little market for this – would need a market mechanism.
Crop residues	Possible better long term soil fertility	Time spent on incorporation	+
Sewage sludge	Possible better long term soil fertility. Sometimes farmers are paid for the application of sludge onto their land	Possible harmful effects of sludge (for those in the upper level of concentration for PTEs [potentially toxic elements]) may reduce long-term soil fertility. Directive 86/278/EEC defines a set of conditions to control potential hazards (including monitoring possible build-up of PTEs)	+ or -
Composting	Possible better long term soil fertility; possible reduction of use of pesticides and fertilisers	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. The profitability depends, among others, on the gate fee a farmer may charge for the dispose of organic waste. Quality of material needs to be good to reap benefit.	+ or -
Improved rotations	Possible better long term soil fertility	-	+
Fertilisation	Improved production	Small increase in fertiliser cost	+ or - as overuse can lead to environmental restrictions
Irrigation	Improved production	Cost of irrigation water and fuel to pump it	+ or -
Bioenergy crops	Depends on price of other fuels. Potential improved long-term fertility	Less flexibility to respond to market changes. Depends on how much subsidy is being paid.	+ or -
Extensification	Potential improved long-term fertility	Less intensive production may lead to reduced per hectare profits	+ or -
Organic farming	Premium paid for organic products. Currently, demand is increasing. However – uncertainties about future development of premia.	Long-term commitment and less flexibility to respond to market changes	+
Convert arable to	Possible subsidies to improved leisure and	Reduced area available for production and less	+ or -

woodland	amenity value of the land	flexibility to respond to market changes	
Convert arable to grassland	Depends on relative product values	Depends on relative product values	+ or -
Convert grassland To arable	Depends on relative product values	Depends on relative product values	+ or -
Convert woodland to arable	More land available for production	Initial clearance costs	+ or -
Grazing land			
Livestock Management	Possibly higher labour costs. Productivity may increase.	Labour costs could be lower. Productivity may decrease	+
Fertilisation	Improved production	Small increase in fertiliser cost	+
Fire protection	Increased labour cost	Product lost to fire less regularly	+ or -
Revegetation			
Abandoned arable land	Possible subsidies for improved leisure and amenity value of the land	Less land for production	+ or -
Farmed organic soils			
Protection and restoration, more shallow water table	Decreased management in keeping water table artificially low. Possible premium for sheep grazing on peat.	Less land for production. In certain regions large negative socio-economic impact likely. Restriction of choice of arable crops.	-

Many carbon sequestration measures have potential positive and 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. For a few, a net positive impact of farm profitability is expected, whilst for at least one, a net negative impact is expected (see Table 9).

As organic soils are the predominant soil types in some agricultural areas, e.g. in eastern and northern parts of Finland, their restoration might have a large impact on the socio-economics, landscape and biodiversity. In practise that would make agricultural production impossible and as agriculture is an important source of income that would have a significant impact on the economy in these areas.

On a European scale, however, only a small fraction of peatlands is used for agriculture; 1% of cropland and 4% of grassland in EU-15 is on peatland. The use of peatlands for farming can not be considered sustainable as carbon stocks significantly decline and further negative environmental side effects appear, such as increased flood risks. There is clearly a need for society to find a balanced and socio-economically acceptable approach to peatland conservation and halt the present levels of peatland destruction (Europe has already lost larger peatland areas than are left now.).

For some measures it is possible to roughly estimate 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 absorption potential of 1.1 t CO_2 ha^{-1}, 22 € could be paid for one hectare of agricultural land (ECCP, 2001). The economic benefits from CO_2 sequestration by themselves could finance additional measures with a positive climate change effect. The agricultural sector could receive additional benefits from "emission trading". In the USA, farmers already have contracts with the industry, offering CO_2 credits resulting from changing their land-use systems. This is a reality in the USA, in spite of the fact that the government has refused to ratify the Kyoto Protocol. If the USA does not participate in the future in the Kyoto Protocol, a lower price per tonne CO_2 is expected on the CO_2 market due to a reduced demand for CO_2 credits (ECCP, 2001). However, with present market prices as low as 3 € per t CO_2 the economic benefit per hectare would be significantly reduced.

Another example of measures that promote the accumulation of organic matter in the soil occurs in some regions of Italy, where under the scope of rural development plans (2000-06), farmers are subsidised for the application of organic fertilisers, in particular composted products, to the tune of between 155 and 220€ ha^{-1} (ECCP, 2001).

Receiving a subsidy may not in all cases be sufficient stimulation for the adoption of a particular measure. In Germany, farmers were not paid enough for the application of sewage sludge to convince them that there is more economic benefit than potential harm by heavy metals.

6 Integration of measures for soil organic carbon sequestration into Agri-Environmental Policy

The reform of the Common Agricultural Policy in the context of Agenda 2000, building on measures introduced in the 1992 reform, established the importance of rural development policies as the second pillar of the CAP, in addition to the first pillar that comprises market support measures. From 2000-2001, new rural development plans were approved including a definition of Good Farming Practice (GFP), based on verifiable standards where soil protection received considerable attention. GFP constitutes a core element of the new rural development policy: the granting of compensatory allowances in less favoured areas is conditional on the respect of GFP and agri-environmental measures provide compensation for undertakings going beyond this baseline. Good Farming Practice is defined as the standard of farming, which a reasonable farmer would follow in the region concerned. It entails in any case compliance with general mandatory environmental requirements resulting from environmental legislation, but Member States may establish additional requirements associated with good practice.

The Common Agricultural Policy already provides opportunities for carbon sequestration in the soil. A number of agri-environmental measures, which are mandatory for Member States, offer opportunities for the build-up of soil organic matter, 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, lowering stock density and the use of certified compost. In line with the integration approach these measures can be developed further to enhance beneficial practices.

Agri-environmental measures aimed at soil protection range from overall farm management systems such as organic farming (including maximum stocking rates) and integrated crop management (ICM) to specific measures such as no-tillage or conservation practices, grassland strips, winter covers, use of compost and the maintenance of terraces. Measures aiming at a reduced use of pesticides, such as integrated pest management (IPM) or promoting balanced rotations can also contribute to improve the condition of agricultural soils.

Within the first pillar of the CAP, the Agenda 2000 reform introduced new environmental protection requirements, whereby Member States shall take the environmental measures they consider to be appropriate in view of the situation of the agricultural land used or the production concerned and which reflect the potential environmental effect (Regulation 1259/99. 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 shall decide on penalties for non-respect of environmental requirements, which may include a reduction or the cancellation of the market support.

An increased level of integration of environmental concerns into the CAP is to be envisaged in future. The Commission is committed to expanding the financial commitment to Rural Development in the review of the CAP. In addition, in line with the proactive approach required for soil protection, the Commission will include soil protection issues in the discussion on the future evolution of good agricultural practices as a policy tool.

6.1 Climate change aspects in the CAP reform proposals

The CAP reform proposals, in their version of 22 January 2003 (COM (2003) 23 final), constitute an important step towards a greater contribution of agriculture to GHG mitigation. They foresee incentives for less intensive and more sustainable agriculture introducing concrete measures that would have a positive effect on GHG emissions. Incentives for extensification and ensuring compliance with environmental legislation are expected to reduce nitrogen fertiliser use and thereby reduce N_2O emissions.

The Commission proposes an aid of EUR 45/ha as a support for energy crops. This will apply for a maximal area of 1 500 000 ha. The aid will only be granted in respect of areas whose production is covered by a contract between the farmer and the processing industry except where the processing is undertaken by the farmer on the holding.

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 be increased 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 below[3]:

Soil protection through appropriate measures:

- Minimum winter soil cover at farm level and for sloping areas and all year round minimum soil cover
- Tillage practices (angle of inclination and length of slopes, nearness to watercourses, direction and timing of ploughing etc.)
- Cropping restrictions in relation to land use where applicable
- Management techniques related to specific crops (vines, olive trees, maize etc.)
- Retain terraces
- Soil tare levels for specific crop (potatoes, sugar beet, etc.)

Maintain soil organic matter levels through appropriate crop rotation practices and tillage techniques:

- Principles and standards for crop rotations including where appropriate for the incorporation of crop residues
- Arable stubble management in particular regarding burning
- Rules where renewal of permanent pasture is undertaken

Maintain soil structure through appropriate machinery use and stocking rates:

- Appropriate machinery use (tyre pressure, use of tramlines, type and timing of agricultural operations etc.)
- Maximum for stocking rate levels to avoid damage to soil structure

Ensure a minimum level of maintenance and avoid the deterioration of habitats:

- Minimum livestock stocking rates or/and appropriate regimes
- Protect permanent pasture through principles and standards restricting use changes
- Retention of field boundaries and landscape features
- Avoiding the encroachment of shrubs on agricultural land.

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.

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[3] See Annex IV to the Proposal for a Council Regulation establishing common rules for direct support schemes under the common agricultural policy and establishing support schemes for producers of certain crops (COM(2003) 23 final - 2003/0006 (CNS))

7 Further Research Needs

The potential for carbon sequestration resulting from technical measures in agriculture as well as the economic, environmental and socio-economic implications of such measures are linked with a high degree of uncertainty. There is a clear need for more research in this field, including the following aspects:

- The potential of management /land-use changes for arable land, peatland and grassland to sequester carbon and to quantify the impacts of other environmental effects *including other greenhouse gases such as nitrous oxide and methane* needs to be further evaluated across different regions in the EU and verified by field experiments.
- Regional data needs to be collected to help establish the potential for carbon to be sequestered according to local conditions (i.e. soil type, climate, current land use), but also to evaluate the effects of policies that may have a regional impact (such as the Nitrates Directive requirements on available manure or whether surplus arable land is available for conversion to grassland). Regional differences may influence the suitability of adoption of certain carbon sequestration measures. For example, conversion of areas of arable land to woodland may be acceptable (i.e. in relation to the aesthetics or landscape planning) in some regions, but not in others.
- More work needs to be done to estimate the social and economic limitations to the implementation of carbon sequestration measures (again on a regional basis). Affects on farm profitability are an important aspect of this.
- There is a clear need for better soil data to produce soil maps and provide reliable estimates of soil carbon stocks under different land use and management and a soil monitoring network to establish the effects of land use, management, soil type and climate on soil C.
- As there are difficulties in comparing data between Member States because of the differences in protocols for sampling and analytical techniques, monitoring efforts should be better co-ordinated with those being undertaken through the recently published Commission Communication of Soil so that consistent approaches between Member States can be adopted.
- There is a continued need to identify and collate relevant data that show that adoption of a measure has a net environmental benefit, as well as a potential to sequester carbon. For example, addition of compost may have the potential to provide carbon sequestration benefits but a sound policy has to address also its quality, e.g. by promoting source segregation of compostable waste. Most current regulations in various Member States include a set of statutory standards based on the need to maintain a high quality of soils and prevent pollutants enter the food chain. The upcoming Directive on Composting, which is mandated by the EC Communication on Soil Strategy will be vital to consolidate such approach, with particular reference to common tight quality requirements to be implemented across Europe and to the promotion of source segregation.
- The agri-environmental scheme provides an important policy instrument to support measures for carbon sequestration. It would be valuable to evaluate to which extent current regional agri-environment measures have an effect on carbon sequestration.
- This report provides a first analysis to the question whether carbon sequestration measures would be cost effective under emissions trading, however, more work needs to be done to establish its potential as a policy mechanism. Questions in relation to carbon permanence

and accounting and who would audit any scheme need to be addressed. Questions are also raised about the sustainability of emissions trading for carbon sequestration in agriculture i.e. what are the net environmental benefits and the costs of undertaking changes versus any monetary gain?

- The negative consequences of soil compaction, such as increased water runoff, are beginning to be seen as a serious problem. There is a clear need for more research and data on the causes of compaction under different farming systems and the effects for carbon sequestration as well as environmental implications.

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