Stocks of C in soils and emissions of CO_2 from agricultural soils in the Netherlands

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ABSTRACT

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In this report we present considerations for the choice of options to calculate and monitor stocks of C in all soils and emissions of CO_2 from agricultural soils in the Netherlands for the Kyoto 1990 baseline and following years. The objective of the study was to prepare data for a national submission according to the Common Reporting Format for C stocks on specific land uses, land use changes en C fluxes according to article 5.2 in the Kyoto Protocol. In this study we report on the whereabouts of the C stocks in order to be geographically explicit, discuss the uncertainties in the inventory and analyse future inventory options. Modeling approaches (e.g. CESAR) where other parameters, process-oriented (fluxes), uncertainty measure can be added are discussed.

Keywords: carbon stocks, carbon fluxes, soils, the Netherlands

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Summary

In this report we present considerations for the choice of options to calculate and monitor stocks of C in all soils and emissions of CO_2 from agricultural soils in the Netherlands for the Kyoto 1990 baseline and following years. The objective of the study was to prepare data for a national submission according to the Common Reporting Format for C stocks on specific land uses, land use changes en C fluxes according to article 5.2 in the Kyoto Protocol. In this study we report on the whereabouts of the C stocks in order to be geographically explicit, discuss the uncertainties in the inventory and analyse future inventory options.
A total of four options for baseline and future monitoring have been examined:

1. Soil maps coupled with soils information system contain elder data (1960-1990), land use since then has changed and may contain an underestimation of spatial variability within map units
2. Dutch soil monitoring network coupled w soil maps Recent data, actual land use, complete coverage, statistically “sound”, uncertainty measures
3. Soils monitoring in forests and other specific regions and ecosystems Partial coverage only
4. Modeling approaches (e.g. CESAR) where other parameters, process-oriented (fluxes), uncertainty measure can be added

The Dutch Soil Monitoring Network has been sampled so far once. Geo-referenced data points (1342 or an average of 1 in each 25 km^2) are linked to groundwater levels, soil map units and actual land use. These locations can easily be re-examined and are stratified for soil type and groundwaterlevel in a random design and in sofar unbiased. Relevant parameter for the Kyoto Protocol in this data base is the measurment of organic matter content of soil layers.

For land use change literature was researched for quantitative data on the carbon stocks and CO_2 emissions form agricultural, forest and nature soil in the Netherlands. This study revealed data based on several estimates, data sources and assumptions. To improve the database, the use of a computer model is suggested. This model is parameterized for five arable crops that together comprise 84% of the area use for arable farming and grassland. It is advise to use this model for the quantification of carbon stocks and changes therin.

1 Introduction

The Dutch government seeks information on the emissions of CO_2 from soils within the framwork of the Kyoto Protocol and the international agreements on reporting emissions of greenhouse gases to the international community through the UNFCCC secretariat in Bonn on the basis of the Common Reporting Format by IPCC. This (quantitative) information is required for the work in the WEB (Working group on monitoring Emissions of Greenhouse gases). This working group will develop a protocol for monitoring of emissions (and sequestration) of greenhouse gases and the associated uncertainties and omissions.

1.1 Objective of this project

This project will provide quantitative data on the carbon stocks and CO_2 emissions from agricultural (and forest and nature) soils in the Netherlands. These data will be based on the main crops in the Netherlands (i.e. grasland and cropland with maize, potato, beets and grains) and forest and nature soils. Further, the organic soils in low areas of the Netherland that have been drained will be reported separately. The data will provide insights in the emissions in 1990 and current emissions and may thus serve as so-called zero measurement.

1.2 Approach and methodology

Within this project, relevant literature data are reviewed and summerized in tables with the areas for the different land uses in the Netherlands and crops in 1990 and for C stocks in soils and emission factors for CO_2. The accounting methodology will be explained and literature sources will be listed. On the basis of the literature data, options to manage changes in C stocks and CO_2 fluxes from agricultural soils by changing activities will indicated and quantified. Any indication as to whether soil carbon stocks are at equilibrium will be explicitly mentioned.

1.3 Reporting conform IPCC methodology

The CRF (Common Reporting Format) is available from UNFCCC and with respect to agriculture and soils table 5a through 5d are relevant. The information on soils that is required in these tables relates to areas for specific activities of land uses (grassland, arable land and forest and nature) or changes therein and emissionfactors for CO_2 and for each of these categories. In the near future, it may very well be possible that this format will change to include so-called 'net-net accounting' where stock changes of carbon are to be reported and possibly with their geographical position to keep track of locations once committed to the Kyoto Protocol.

2 Methodology and approach for the calculation and mapping of the C – stocks in soils in the Netherlands

2.1 Options for methodology and approach to calculate C – stocks

A calculation of the C stock in soils in the Netherlands can be made following different strategies (see table 2.1):

1. On the basis of the Soil Map of The Netherlands, scale 1 : 50 000 and representative descriptions of the soil profiles that were recorded in the period 1960 – 1990 and the Soils Information System.
2. On the basis of the recent Dutch Soil Monitoring Network (DSMN) (de Gruijter et al., in prep.) carried out between 1990 and 2001 following the different groundwater levels indicated on the Soil Map of The Netherlands, scale 1 : 50 000.
3. For forests results on the basis of a project on 'Effects of acid deposition on 150 forest stands in the Netherlands' on the chemical composition of the humus layer, mineral soil and soil solution (De Vries and Leeters, 2001).

2.1.1 Topographic Soils Map coupled with the Soils Information System (BIS)

The first option to assess the C stock in soils of the Netherlands in 1990 is to use the documentation set of representative descriptions of soil profiles for all units of the Soil Map of The Netherlands, scale 1 : 50 000 (de Vries, 1998). Representative descriptions are derived from soil descriptions in the Dutch Soil Database (BIS). The inventory of soil descriptions have been made in the period 1960 – 1990 and organic matter content was assessed using soils samples taken during this time from a range of profiles and soils. The advantage of this approach is that it follows international standard procedures such as used by FAO (FAO, 1988) where estimates are calculated on the basis of measurements in representative soil profiles. This approach would be most comparable with approaches taken abroad (.

The disadvantage of this approach is that the locations of representative descriptions are no longer known and therefore they cannot be re-examined. Only original land-use at the time of visit of the location is available. During the sampling period 1960 – 1990 many changes in land-use and in (deep) soil cultivation have taken place, which may have seriously affected the C stocks and C dynamics. The descriptions of profiles therefore may be outdated and not represent current profiles and C stocks in 1990 or thereafter.

2.1.2 Dutch Soil Monitoring Network (DSMN)

The second option to assess the C stock in soils in the Netherlands in 1990 is to use the Dutch Soil Monitoring Network (DSMN) of the Soil Map of The Netherlands, scale 1 : 50 000 (de Gruijter et al., in prep). This survey was carried out between 1990 and 2001 and is based on surveys on each of the 9 clusters of different groundwatertable classes. For each groundwatertable class (Van het Loo, 1997, 1998; Visschers, 1998, 1999a, 1999b, 2000, 2001, 2002) survey reports were written. The purpose of this program was to realise an upgrading of the Soil Map of The Netherlands (scale 1 : 50 000) by more quantitative, detailed and comprehensive descriptions of map units. In the surveys on the different groundwaterclasses at a total of 1392 sites profiles have been described and soils were sampled for chemical analysis including analysis of content of organic matter. The locations of these sampling sites were known, because they were chosen by random selection of co-ordinates in each cluster of map units of a groundwaterclass. Each groundwaterclass has its own stratification. Strata are sub regions in a cluster and are chosen (together with the choice of sample sizes) on homogeneous (soil) groups to obtain sufficiently accurate estimates of certain soil characteristics.

In a number of surveys, separate strata for nature ecosystems and forests are identified on the basis of the ALBOS database (de Vries and Al, 1992).

A good estimate of the C stock in soils is obtained on the basis of the organic matter content, the thickness of soil layers en bulkdensity functions. For the calculation of the C stock, a C concentration of 50% of organic matter was assumed even though the mean C concentration for the top of organic soils was calculated at 53.6% in the Dutch Soil Database.

As all strata by definition are coupled to the Soil Map of the Netherlands (1 : 50 000), C stocks in a stratum can be linked to elements on the map and a map with C stocks can be drawn (see figures 2.1, 2.2 en 2.3). In all but groundwater class III, separate strata exist for nature areas and hence the C stock in nature areas can be separated from the C stock in agricultural areas.

2.1.3 Monitoring soils in forest ecosystems (FIMCI)

In order to gain more insight in the regional variability of the soil and soil solution composition below forests in relation to forest vitality, a nation-wide assessment was made of the chemical composition of the leaves (needles), humus layer, mineral topsoil and soil solution in 150 forest stands[1]. The choice of the locations was largely determined by 118 forest stands selected by the National Institute of Public Health

[1] The resulting 150 forest stands include 45 stands of Scots pine, 30 stands of oak and 15 stands of black pine, Douglas fir, Norway spruce, Japanese larch and beech. A total of eleven stands were later selected to be part of the monitoring system in the context of the International Co-ordinated programme of Forests, being monitored since 1994. At each site an indication of stand characteristics, affecting the deposition, was made such as tree height, canopy coverage, distance to the forest edge and surrounding land use. Furthermore, a description of soil type and ground water class was made. Most forests were located on podzolic soils, i.e. Cambic, Carbic and Gleyic Podzols, and Haplic Arenosols and to a small extent on relatively rich sandy soils. Ground-water levels are mostly deep.

and Environmental Protection (RIVM) for the determination of ground-water quality at the phreatic level in 1990. From this database, 89 stands were selected. The additional 61 stands were selected by aiming at (i) an optimal range in deposition level, (ii) inclusion of major tree species, proportional to the national occurrence and (iii) an optimal range in site conditions, i.e. soil type and ground-water level.

At each site, composite samples were taken, consisting of 10 sub-samples for the humus layer (divided in a L& F and H horizon) and of 20 sub-samples for the mineral soil at depths of 0 - 30 cm, 30 - 60 cm and 60 - 100 cm. For every sub-sample the thickness of the litter (L), fermented (F) and humus (H) horizon plus the total thickness was noted. Where the thickness of the humus horizon was more than 1 cm, the humus horizon was sampled. Among other chemical analyses, C content was measured in both humus and mineral layers.

Table 1. Databases and approaches available to assess soil carbon stocks in the Netherlands.

	Set of representative soil profiles derived from the Dutch soil profile database (BIS) to describe the Soil Map of The Netherlands, scale 1 : 50 000.	Dutch Soil Monitoring Network (DSMN) of the Soil Map of The Netherlands, scale 1 : 50 000.	Monitoring soils in forest and nature ecosystems (FIMCI)
Is specification per region possible?	Yes, the set of representative soil profiles is describing all map units covering the total country though the used measurements were not part of a random set.	Yes, every entry and sample point is labelled to specific categories (clusters and strata) and to map units at the Soil Map of The Netherlands, scale 1 : 50 000 and can be re-examined and analysed	Yes, though only for forest soils
Is specification per land use category possible?	Yes, overlay of the Soil Map of The Netherlands, scale 1 : 50 000 with the Land Use Map of the Netherlands (LGN-3) is possible.	Yes, overlay of the Soil Map of The Netherlands, scale 1 : 50 000 with the Land Use Map of the Netherlands (LGN-3) is possible. Also at each sample point, land use is recorded.	Only for forested ecosystems
How is C stock calculated?	On the basis of characteristic organic matter content top soil (0 – 30 cm) and other horizons and referring to representative soil profiles	By calculating means of measured organic matter content in top soil (0 – 30 cm) and other horizons of clusters and strata with known area.	Measurements of organic matter and C in litter layer and mineral soils to different depths
Is the measurement date fixed and known?	Yes, covering a period of 30 years from 1960 – 1990	Yes, each entry is exactly positioned on topographic map; measurements from the period 1990 – 2001	Plot location is known and so is time and date of sampling (1995 or 2000)

2.2 Choice of methodology and approach

For this project, the C stocks for the Netherlands have been established on the basis of the Dutch Soil Monitoring Network (DSMN) of the Soil Map of The

Netherlands, scale 1 : 50 000. For each level of stratification (i.e. subdivision of The Netherlands to obtain hydrologically (clusters) and pedologically (strata) similar but larger units. In this way as much strata, which are practically easy to sample and also giving statistically sufficiently accurate estimates of certain domains of interest, were created. This DSMN includes nature and forest areas.

Average C stocks have been calculated for the top 0 – 30 cm soil layer. This layer is considered to be the most active part of soil in terms of CO_2 emissions. For all strata with a larger part of organic soils (i.e. more than half of the upper 80 cm of the soil profile is organic (FAO, 1988) C stocks for 0 – 120 cm have been calculated as here watertable management may create conditions for oxidation of organic matter in deeper layers than the top 30 cm. All C stocks in individual strata were coupled to the Soil Map of The Netherlands, scale 1 : 50 000 to create a spatially explicit map of C stocks in the Netherlands (figure 2.1).

A map for C stocks for different land use (i.e. grassland, arable land and forest or nature) or soil type (i.e. organic soils) was made by coupling the C dataset to the land cover database of the Netherlands (LGN3) (de Wit et al., 1999) (results in figure 2.2, 2.3 and 2.4). The land cover database is merely build from satellite images. So the accuracy is not 100 but maximal 80 percent as smaller elements such as ditches or dust roads may not appear as water but are included with the adjacent land use. Also, the estimates from satellite images may differ from statistical data in that all grassland including private lawns, sportsfacilities and parks are included whereas they are not in the statistical assays.

In this calculation, units on the soil map that are not coded for groundwatertable such as land in riverbeds or seashores outside the dikes were not taken into account. The exception to this rule is the hills in Limburg (far southern part) of the Netherlands as they are included despite lack of groundwaterclass code.

2.3 Soil carbon stocks in the Netherlands

The total C stock in the top layer (0 – 30 cm) of the Dutch soils on the basis of the Soil Map of The Netherlands (scale 1 : 50 000) and the DSMN database (for approximately 90% of the total area) is calculated at 286 Tg C with a 95% range of accuracy on measured organic matter of 280-293 Tg C. Then the DSMN datatbase is coupled with the land cover database of the Netherlands (LGN3). Landuse of three categories i.e. grassland, arable land and nature, is identified. This gives an estimated C stock under grassland of 148 Tg C (1 426 000 ha), on arable land of 85 Tg C (920 000 ha) and in forest and nature of 31 Tg C (445 000 ha) (figure 2.1 and 2.3, table 2.1). The land cover database is younger that the soil map and as a consequence some areas or soils may not match completely anymore. This is a source of small errors in the estimates on soil C. In table 2.1 the rural area in the landcover database is taken into account. Because of the inaccuracy of the land cover database the calculated areas may hold some inaccuracy. The reported areas in use for agricultural

grass and arable land in 1990 (CBS, 1999) are about 28.5% and 17.6% smaller respectively; 1 100 000 ha and 780 000 ha.
The strata with a larger part of organic soils (15% of the total surface area = 422 000 ha) contain (in the layer 0-30 cm) 23% or 66 Tg C. In the layer of 30 – 120 cm they contain 142 Tg C. So the total C content of organic peat soils (0 – 120 cm) is 208 Tg C and accounts to approximately 50% of the active organic C (0 – 30 cm of all soils and 0 – 120 cm in organic soils) (figure 2.2).

Table 2.1 Calculated C stocks in Dutch soils for different categories of land use, i.e. grassland, arable land and forest and nature areas and the total for these categories.

	Area (ha)		C stock 0 – 30 cm (Tg C or Mton C)	
	Ha (*1000)	%	Tg C	Ton C per ha
Grassland	1426	51	148	103
Arable land	920	33	85	92
Forest and nature areas	445	16	31	69
Total[1]	2791	100	264	94

[1] A total of 1392 measurement were taken; 282 in arable land, 226 in forest, 749 in grassland and the remaining are in horticultural land, bare soils and waste land, orchards and parks. The categories grassland, arable land and forest and nature areas contain 264 Tg C out of a total of 286 Tg of C (92%)in the top 30 cm soil in the Netherlands.

2.4 Monitoring soil carbon stocks in the Netherlands

The DSMN database gives the possibility of starting a monitoring program on earlier sampled points. In areas with organic soils it is difficult to determine the change in C stock. Although the C-content of the topsoil is not changed, still there is the opportunity of C-loss by oxidation because of altitude decreasing. So it is necessary to measure the exact altitude levels as well. Another possibility is to make use of the Map with Peat thickness classes of the Netherlands scale 1 : 50 000 which mapping is finished in 2002.

Carbon stocks in the topsoil (0 - 30 cm) in relation with landuse

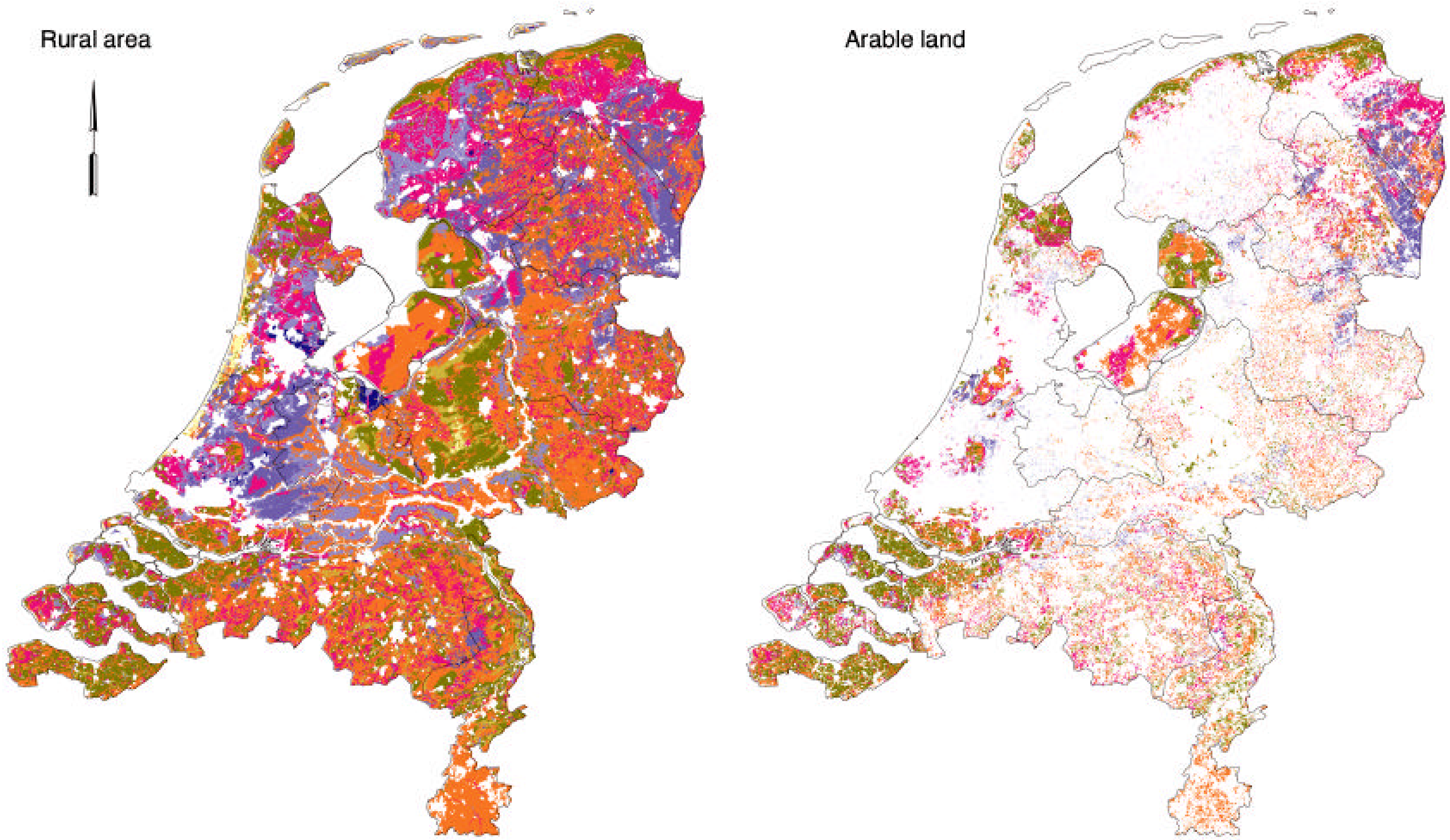

Figure 2.1 Carbon stocks in soils in the Netherlands (0 – 30 cm) on the basis of the Soil Map of The Netherlands, scale 1 : 50 000, the DSMN database and the land cover database of the Netherlands (LNG3) (left) and carbon stocks in soils in arable land in the Netherlands(right)

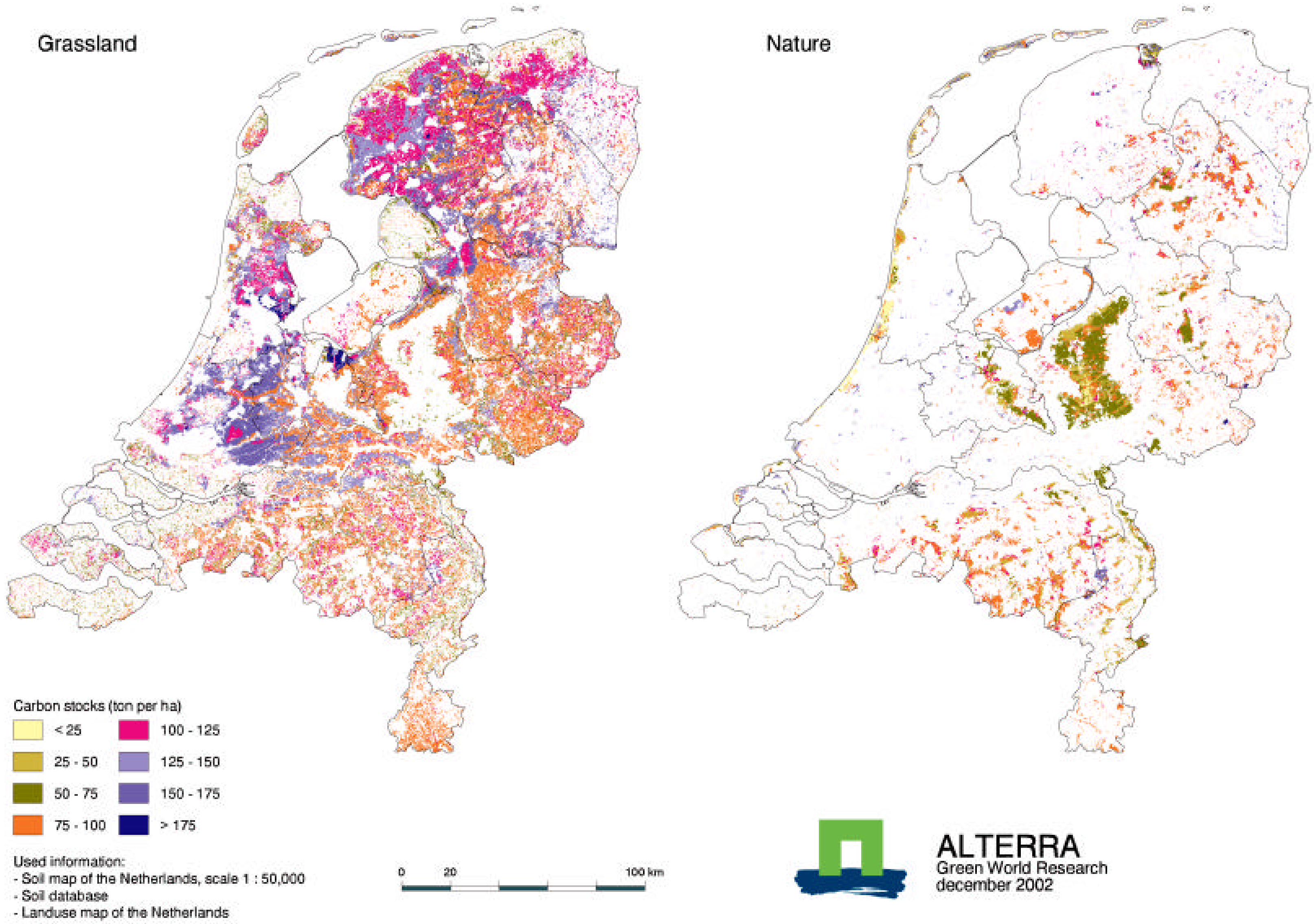

Figure 2.2 Carbon stocks in soils in the Netherlands (0 – 30 cm) for grassland and forested and nature areas on the basis of the Soil Map of The Netherlands, scale 1 : 50 000, the LSK database and the land cover database of the Netherlands (LNG3)

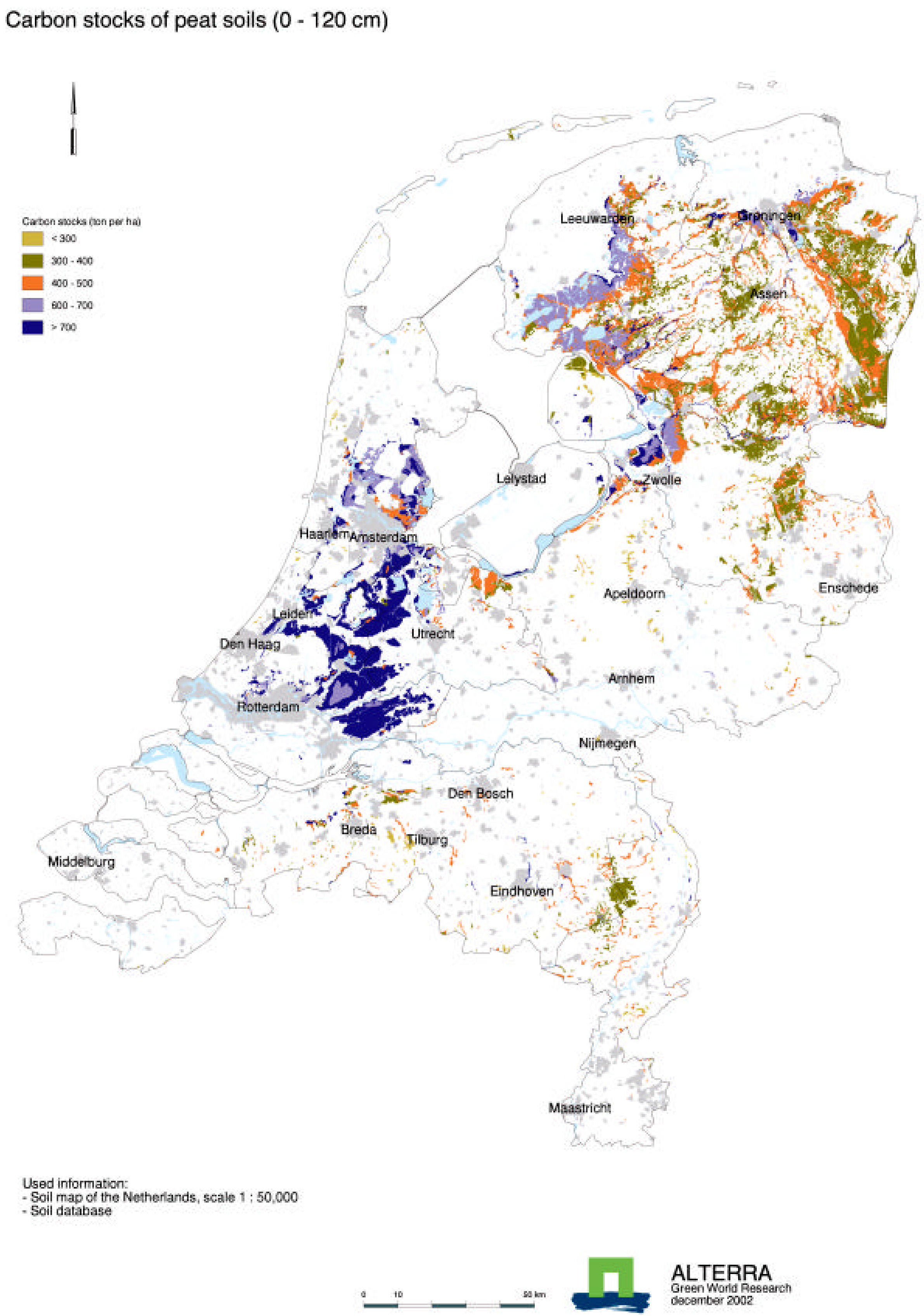

Figure 2.3 Carbon stocks in soils in the Netherlands (0 – 120 cm) for organic soils on the basis of the Soil Map of The Netherlands, scale 1 : 50 000, the DSMN database and the land cover database of the Netherlands (LNG3)

2.5 Carbon stocks in forests in the Netherlands

2.5.1 Pools of organic matter in the humus layer of forests

Pools of organic matter in the *humus layer* of forest soils in the Netherlands vary mostly between 20 –110 ton.ha^{-1} (De Vries and Leeters, 2001). This is an indication that part of the forest stands in the Netherlands are in the phase of organic matter accumulation in the humus layer (see e.g. Mc Fee and Stone, 1965; Youngberg, 1966 and Van den Burg and Schoenfeld, 1988). In most forest stands, humus accumulation stops when the humus layer pool approaches a value of ca. 80 - 100 ton.ha^{-1} (Van den Burg and Schoenfeld, 1988) unless the conditions for decomposition are extremely unfavourable (e.g. very wet circumstances). Approximately 50% of the stands have pools in or above this range and would not further accumulate organic matter in the humus layer. The total C pool in the humus layer horizons is estimated at 37 ton C per ha (table 2.2). The C – stocks in the humus layer under seven major tree species vary little and is 34 and 41 ton C per ha except for the C – stock for Black pine (table 2.3).

Table 2.2 Median values of the carbon pool in the humus layer horizons on sand

Horizons	C pool (ton.ha-1)
LF	32.9
H	10.0
LFH	36.5
Total	*36.8*

Table 2.3 Median values of the carbon pool in the humus layer under seven major tree species on sand

Tree species	C pool (kg.ha^{-1})
	C
Black pine	22718
Douglas fir	34028
Oak	36122
Norway spruce	36207
Scots pine	37984
Japanese. larch	40359
Beech	40829

Comparison of an assumed maximum organic matter pool of ca 50 - 100 ton.ha^{-1} (depending on the conditions for decomposition) and a litterfall rate of ca 2 - 4 ton.ha^{-1}.yr^{-1} (De Vries et al., 1990) indicates an average annual litter decomposition rate of ca 1.5 - 8%. Since ca 40% of the freshly fallen leaves and needles mineralises during the first year (Janssen, 1983), the long-term decomposition rates vary between ca 1 and 5%. This is in the range of organic matter decomposition in the topsoil of agricultural soils in the Netherlands, which equals on average ca 2% per year (Kortleven, 1963).

2.5.2 Pool of organic matter in mineral soil of forests

Compared to the humus layer, the organic matter contents in the mineral soil are much lower, but the pool of organic matter is generally twice to thrice as large. Both the content and pool of organic matter generally increased from Haplic Arenosols < Cambic Podzols < Fimic Anthrosols < Dystric Gleysols < Gleyic Podzols < Umbric Gleysols. This illustrates that the organic matter content increases when the circumstances for decomposition are less favourable; in this case too wet or too acid.

The C stock in the mineral soil is generally twice to thrice as large as in the humus layer, due to the much higher bulk density of the mineral layer and varies quite strongly between the six soil type considered (table 2.4). C stocks increased from Haplic Arenosol < Cambic Podzol < Gleyic Podzol < Fimic Anthrosol < Dystric Gleysol < Umbric Gleysol. This is mainly due to the increasing amount of organic matter in this direction of soils, which is clearly reflected in the C pools.
The total carbon stock for forest soil including mineral soil and humus layer in the Netherlands is estimated at 33.6 Mton C. This calculation is based on

- The average carbon content of humus layers and mineral soil horizonts upto – 100 cm (table 2.5)
- measurements in 70 – 80 of the total forested area in the Netherlands that give 24.7 Mton C in 73.4% of the total Dutch forests
- extrapolation to estimate the C stock in all forested soils in the Netherlands by assuming that the C stocks in the remaining soils and species are similar to the average for the forest on sandy soils with the species listed in table 2.2.

This extrapolation gives a 33.6 Mton C in the total forest soils in the Netherland and this would give an average C content per ha of just over 100 ton C.

Table 2.4 Median values for the total pools of C, N and P in the mineral topsoil for six soil types in sand

Soil type	C pool ($ton.ha^{-1}$)
Haplic Arenosol[1)]	26.7
Cambic Podzol	57.5
Fimic Anthrosol	69.1
Dystric Gleysol	76.2
Gleyic Podzol[2)]	76.5
Umbric Gleysol[3)]	99.0

[1)] including Gleyic Arenosols
[2)] including Carbic Podzols
[3)] including organic rich soils

Table 2.5 Calculated C stocks in Dutch forest soils and humus layers. The estimation is based on measured C pools in 150 forest stands that represent 73.4% of the Dutch Forest Area of 320 000 ha. The calculation is based on average value of C in litter plus mineral soil layer (0 – 30 cm) in different combinations of trees and soils multiplied by the area of these soils on the basis of the overlay of forest statistics and soil map.

Soil type	**opp(%)**	**C pool (kg/ha)**	**opp (ha)**	**kton C**
Haplic Arenosol[1)]	14.8	69632	47360	3298
Gleyic Podzol[2)]	34.8	116070	111360	12926
Cambic Podzol	11.4	95751	36480	3493
Fimic Anthrosol	8.2	109992	26240	2886
Umbric Gleysol[3)]	4.2	152889	13440	2055
total	73.4		234880	24657

2.6 Discussion and conclusions on C stocks in soils

For agricultural soils the data on soil carbon presented in this study are based on the main crops in the Netherlands, i.e. grassland and arable land and on forest and nature areas. A special issue was the organic soils in low areas with peaty and organic soils that have been and are continuously drained. Three databases and approaches are options to assess soil carbon stocks:

- Based on the topographic soil map coupled with the soils information system;
- Based on the Netherlands soil monitoring program
- Based on the monitoring soils in forest and nature ecosystem.

The second option seems to be the best one. But even for this option the accuracy is maximal 80 percent. The total C stock in the top layer (0-30 cm) is calculated at 286 Tg C. The C stock under grassland is 148 Tg C, on arable land 85Tg C and in forest and nature is 31 Tg C. An other problem is that model underestimate the land uses areas. E.g. the areas for agricultural grass and arable land estimated by statistics in the Netherlands are about 28.5% and 17.6% smaller than calculated on the basis of the land use maps.

The pool of organic matter in the humus layer and in mineral soil of forest is estimated too. To do this the average value of the humus layer and the mineral soil is multiplied for several combinations with the soil areas for wood and nature. This was only possible for half of the total forested area and resulted in an estimation of a C content of 33.7 Mton for the total forests.
In the Dutch literature there is a wide range in the annual CO_2 emissions from the low wet areas in the western part: 0.1 to 7.0 ton C/ha. One of the elements of uncertainty is the exact size of the total area and of the amount of peat present. This estimates on peatland area range from 294.000 ha to 450.000 ha. In the Netherlands no database or map with thickness of peat layers is available (Rienks et al., 2002).

3 CO_2 emissions from soils in lower peat containing part of the Netherlands

In the western part of the Netherlands a relatively large part is peat soils that are used for intensive dairy farming and agriculture. The origin, quality and quantity of these peat soils is highly variable. Thickness of the peat layers varies from 1 to several upto 12 meters and some of the peat is covered by layers of clayey soil.

3.1 Current estimates of CO_2 emission from lower peaty soil

Relevant greenhouse gas emissions in the peat soils include carbon dioxide, methane and nitrous oxice. Relatively few data are available on emissions. In a recent review annual emissions of CO_2 from low peat soils in the Netherlands are reported to range from 0.1 – 7.0 ton C ha^{-1} j^{-1} (Burgerhart, 2001). Typically two approaches have been taken in estimating CO_2 emissions, i.e. flux measurement using Eddy co-variance techniques (Langeveld et al., 1997; Dirks, 1993; Dirks and Goudriaan, 1994 and Hensen et al., 1998) and changes in ground surface level following oxidation of peat (Wolf, 1990; Hendriks, 1991). These estimates have been summarized in table 3.1) and are based on a wide range of methods, locations and time periods.

Table 3.1 Overview of literature sources and estimates on CO_2 emissions from lower drained peat soils in the Nethelands

Method	**Location**	**Relevant periode**	**CO_2-emission (ton C $ha^{-1}.j^{-1}$)**	**Source**
Flux measurements on CO_2	Zegveld, drained grazed pasture on peat	March – October 1994	ca. 3.0	Langeveld et al. (1997)*
Flux measurements on CO_2	Cabauw, drained grazed peat pasture with thin clay cover	1994 – 1997	0.1 – 3.3 (with average of 1.8)	Dirks (1993)* Dirks&Goudriaan (1994)* Hensen et al. (1998)*
Measurements on lowering ground surface level indicate 2 – 6 mm j^{-1} (Schothorst)	Zegveld, drained grazed pasture on peat (forest peat)	Average weather	2.3 – 7.0	Wolf (1990)*
	Netherlands, drained grazed pasture on peat (forest peat)	Average weather	1.7 – 5.1	Hendriks (1991)

* Bronnen in Burgerhart (2001)

Differences in the results of fluxmeasurements such as the location Zegveld and Cabauw (table 3.1) or between successive years are most likely caused by peat quality (eutrophic or oligotrophic peat) or other environmental conditions such as drainage intensity and level, weather conditions and the absence or presence of a mineral (clayey) cover. In general, the depth to which the peat is drained is most important to

CO_2 emissions as oxidation is an aerobic process and restricted to drained peat soils. Second, eutrophic peat will decompose 2 to 3 times faster than oligotrophic peat will (Hendriks, 1993). Weather impacts are mostly through temperature and rainfall pattern. Hendriks (1993) reported Q_{10}-values for different qualities of peat in the range of 2.4 – 5.6; this means that at 10 degrees higher temperatures, peat may decompose 2.4 – 5.6 times faster. Rainfall will impact soil moisture content and groundwaterlevel and the more moist the slower decomposition will be. Finally, a mineral soil (clayey) cover will reduce the decomposition of underlying peat (Schothorst, 1979).

According to Burgerhart (2001) the low emission in Cabauw in 1996 and 1997 as compared to 1994 and 1995 could be the result of lower temperatures and less rainfall. Another cause could relate to the watermanagement that would have maintained higher levels during 1996 and 1997. Due to peat oxidation the surface level will drop. Usually once every 5 or 10 years the water table level will be adjused to changes in shrinkage and a new surface level. This may suddenly expose new peat layers to aerobic conditions and cause differences between successive years. The decomposition rate of peat will drop with time (Jansen, 1986) and may fall in four years by 2 or 3 times the initial rate. Both water management and differences in rate of peat oxidation may lead to strong annual variations. However, the continued water management where specific water levels will be maintained to allow access for agricultural practices will eventually lead to oxidation of vast amount of organic mater.

Another method to estimate CO_2 emissions from drained peat soils is through the estimation of the loss of organic matter on the basis of changes in surface level and soil shrinkage. The advantage of this method is that the estimate is based on long term data where annual differences in weather conditions do not longer dominate. Furthermore, data for plot and regions are available whereas flux measurements are most likely point sources and relate to local conditions. A disadvantage may be that estimates are indirect and based on multiple measurements of organic matter content, C-content and bulk density. These parameters are usually well known and can be well estimated (see table 1

Tabel 3.1 gives estimates by Wolf en Hendriks on the basis of long term lowering of surface level for three locations whit eutrophic peat. The differences can be easily explained on the basis of differences in calculations between Wolf and Hendriks. Wolf uses a C content of 58% of the mass whereas Hendriks uses 43% of the mass (55% of the organic matter of the peat and 75% of the mass would be organic matter.). The approach by Wolf who does not account for mineral parts in the peat and assumes that all material is organic matter may lead to an underestimation of CO_2 emission of 4%.

Hendriks (1991) indicated that the depth to which the peat is drained is a crucial factor. For each 10 cm drainage, the surface will lower by approximately 1 mm (1%) per year. According to Schothorst, 60% (short term) to 85% (long term) would be due to oxidation and the remainder to shrinkage. A literature assessment by Baas

(2001) provides an estimate of 1.8 mm for each 10 drainage per year (sd = 0.9 mm, n = 10). On this basis one could calculate a loss of organic matter through oxidation of $(0.6 – 0.85 \times 1.8 \times 10^{-3} \times 10^{4} \times 200 \times 0.75 \times 0.55)$ 0.9 – 1.3 ton C per ha per year for each 10 cm of lowering the water table through drainage. This may to date be considered as the best available estimate as it is based on long term measurements of lowering of the surface area throughout the area.

3.2 Estimates for the CO_2 emission from the entire peat soil area

An estimation of the total CO_2 emission from the entire peat soil area in the Netherlands should consider:

1. The overal area of active peat soils
2. The emission of CO_2 in relation to watermanagement and relate to peat quality
3. The actual watermanagement for peat soils

Not all data in literature aree on the total area for peat soils in the Netherlands. Hendriks (1991) uses the soils map of the Netherlands and give 294 000 ha. Other authors such as Hensen et al. (1998) use 450 000 ha. The difference between these two estimates is in the soils that have organic layers on top of a mineral soil. One could argue that these soils are (no longer) active peat soils in the sense that water table mangement will not make new peat layers accessible. Yet, the organic matter in these soils will continue to decompose though at a much lower rate. For that reason we do not include them in our calculation here. The actual water table management could be very well estimated on the basis of detailed data from water managers. For our calculation here, we assume an average drainage level of 50 cm below surface.
The annual CO_2 emission from peat soils in the Netherlands on the basis of these assumptions can be calculated at 1.3 – 1.9 Mton C per hectare per year or 4.8 – 7.0 Mton CO_2 per year (.9 – 1.3 ton C per ha per year times 50/10 times 294 000 ha times 10^3).

3.3 Improving the estimates of carbon dioxide emissions

A more detailed estimate would require the availability of a well established relationship between water table management and changes in ground surface level and peat quality and land use. A GIS database for the entire peat area in the Netherlands would be necessary and inlcude:

1. Area of peat including those soils where peat layers are less then 40 cm
2. Map with thickness of peat layers (may range from centimeters to meters)
3. Peat quality to assess differences in decomposition rates
4. Water table management and surface level changes
5. Land use.

3.4 Options for managing carbon dioxide emissions from peat soils

Options for changing the emissions of carbon dioxide from organic peaty soils in the Netherlands include:

1) Management of groundwater level
2) Lowering groundwater levels
3) Expansion of infrastructure
4) Climate change.

Managing groundwater levels and maintaining higher levels (wetting) may reduce the oxidation of peat layers in soils and so limit emissions of carbon dioxide. Effects may be quantified on the basis of documented changes between lower groundwater levels and shrinkage of soils and lowering soil surfaces in the past.

In those case where drainage reduces soil and groundwater levels the surface levels will follow the groundwater level will follow the absolute surface level. As a result the water intrusion from soils (so called kwel) will increase and reduce the oxidatin of peat.

In case of building activities and infrastructure expansion on peat soils these will be covered with sand layers. As a result of the creation of anoxic conditions the rate of oxidation of peat will slow down. The change in this lowering of oxidation will depend on the thickness of the sand layer that is deposited on the peat, the surface area and the management of water levels in the area.

The anticipated temperature rise in the decennia to come may affect the rate of oxidation of peat (Q_{10} values will increase). Hendriks (1993) calculated that peat oxidation may increase by 10-13 % for for each degree celsius that the temperature may rise. This effect will be most pronounced in the summer season when soil water levels are kept low. However, if rainfall in the summer season will be higher as a result of climate change, this will negatively impact the rate of oxidation of peat in deep drained peaty soils. The effects of these scenarios on peat oxidation may vary and can be best assessed by using a simulation model and proper parameterization.

4 Changes in the stocks of organic matter in soils in the Netherlands

4.1 Introduction

In agricultural land, the great majority of carbon is storen in soil. Using statistical relationships between agricultural land-management practices and changes in soil organic carbon, Smith et al. (2000) conclude that there is considerable potential for carbon dioxide mitigation by agriculture. However, a substantial spatial component in the net sequestration may be expected because of regional differences in soil, climate, land cover and crop yields. The CESAR model (Carbon Emissions and Sequestration by AgRicultural land use, Vleeshouwers et al., 2001) was developed to simulate changes in the carbon content of plant production systems. The model includes the effects of crop (species, yields and rotations), climate (temperature, rainfall and evapotranspiration) and soil (carbon conten and water retention capacity) on the carbon budget of agricultural land.
The CESAR model focuses on carbon stocks and fluxes in soil organic matter. The model calculates carbon input to the soil from plant residues and carbon input from the soil by decomposition of the accumulated organic matter in the soil. In specific situation, it may be useful to estimate carbon stocks and carbon fluxes in the more transient carbon pools in plant production systems, viz. standing biomass, crop residues with a short residence time and harvested biomass.

4.2 Cesar calculations on C fluxes and C dynamics

The model is parameterized for five arable crops, that together comprise 84% of the area used for arable farming in the Netherlands, and for grass. The arable crops are winter wheat, summer barley, potato, sugar beet, and silage maize. The crops are characterized by 5 parameters,

- average day of canopy closure
- average day of crop harvest
- average yield
- harvest index, i.e. the biomass removed from the field expressed as a fraction of total (above and below ground) biomass
- the humification coefficient of the non-harvested biomass (*h*), i.e. the fraction of the non-harvested biomass that remains in the field one year after the crop has been harvested.

Parameter values that are applicable to the Netherlands are shown in Table 1. Average yields of the arable crops were taken from agricultural statistics (Landbouw-economisch Instituut, 1999). Harvest indices and humification coefficients of the arable crops were derived from data supplied by Consulentschap in algemene dienst voor Bodemaangelegenheden in de Landbouw (CBL) (1980). In the derivation of the harvest indeces it was assumed that the amounts of crop residues reported by CBL

(1980) still relate to present day crop yields. In the two cereal species and in sugar beet, two options are given. The first option is that the straw of the cereal species, and the leaves and beet tops of the sugar beet are removed from the field. The second option is that the straw of the cereals, and the leaves and beet tops of the sugar beet are ploughed under. In the calculations, it was assumed that the harvest index is a species-specific constant that is not affected by the yield level of the crop. In contrast with the arable crops, grass is harvested several times during the season. The average yield was taken from Commissie voor de Samenstelling van de Rassenlijst voor Landbouwgewassen (2000), and the harvest index was assumed to be 0.5 (Ad Schapendonk, pers. comm.). It was assumed that there are five monthly harvests, between 1 June until 1 October. For the humification coefficient of non-harvested grassland biomass, a value of 0.33 was assumed. For all crops, the life-time of the harvested product was given the default value of 1, since it is considered that in the long run there will be no built-up of harvested products.

4.3 Decomposition of crop residues

When the crop is harvested, stubble and roots remain in the field. In the crop residues two fractions are distinguished: a fraction that decomposes quickly, and has disappeared after one year (equal to 1-*h*), and a fraction that is added to the stable organic matter pool in the soil, which decomposes slowly (equal to *h*). In the Netherlands, a fraction of 2% of the slowly decomposing organic matter decomposes yearly (Wolf & Janssen, 1991a). In the model, 99% of the fast decomposing fraction is assumed to decompose during the first year after harvest. Decomposition rates are dependent on the temperature. In the calculations, the temperature to which the decomposition rates apply is the average temperature in the Netherlands (assumed to be 10 °C). According to Van der Linden, Van Veen and Frissel (1987), the Q_{10} of decomposition of organic matter in the soil equals 4. Amounts of organic matter are calculated into amounts of carbon, assuming that the average carbon content of plant material is 45%, and the carbon content of slowly decomposing soil organic matter is 58% (Wolf & Janssen, 1991a).

The model does not include the supply of organic manure in the calculation of carbon fluxes of agricultural land. In the model, the decomposition rate of soil organic matter is not affected by soil tillage. The latter may imply that the decomposition rate in arable soils is somewhat underestimated compared to that in grassland.

4.4 Steady states

Steady state carbon pools were calculated for 14 regions in the Netherlands (Table 2). Calculations were based on regional crop yields (except for grassland, for which only the average yield in the Netherlands was available), and regional temperature data from five weather stations in the Netherlands (summarized in Table 4.3).

Table 4.1. Crop parameters used in the model. Harvest index is related to total above-ground and below-ground dry matter. For the cereal crops and for sugar beet two options are given (see text).

crop species	winter wheat	summer barley	potato	sugar beet	silage maize	grassland
day of canopy closure/ start of growing season	1 April	1 June	15 June	1 June	15 June	1 April
day(s) of harvest	1 August	1 August	15 Sept	1 Nov	1 October	1 June, 1 July, 1 August 1 Sept, 1 October
Option 1						
average yield (t d.m. ha^{-1})	10.5	7.2	8.9	17.6	12.2	12.0
harvest index	0.67	0.63	0.69	0.92	0.86	0.5
humification coefficient	0.32	0.31	0.22	0.25	0.34	0.33
Option 2						
average yield (t d.m. ha^{-1})	7.2	5.1		13.1		
harvest index	0.46	0.45		0.69		
humification coefficient	0.31	0.31		0.21		

Table 4.2. The calculated average steady state amount of carbon in the crop-soil system (t_C ha^{-1}). For the cereal crops and sugar beet two options are given (see text). Throughout the paper, t_C denotes tonnes of carbon, $t_{o.m.}$ denotes tonnes of organic matter.

	winter wheat		summer barley		potato	sugar beet		silage maize	grassland
Option	*1*	*2*	*1*	*2*		*1*	*2*		
Bouwhoek en Hogeland	52.7	82.0	43.0	62.6	27.0	15.8	40.6	21.6	128.2
Veenkoloniën en Oldambt	50.1	77.4	42.4	61.4	26.4	16.2	41.6	24.6	128.2
Noordelijk weidegebied	50.1	77.4	38.3	55.3	26.0	15.4	39.2	22.8	128.2
Oostelijk veehouderijgebied	47.6	73.9	40.0	57.7	29.0	15.8	40.6	27.4	128.2
Centraal veehouderijgebied	38.3	59.4	35.6	51.2	25.7	14.4	35.8	24.5	114.1
IJsselmeerpolders	48.7	75.6	41.3	59.9	27.5	18.3	45.8	31.0	118.4
Westelijk Holland	50.2	77.7	39.1	56.5	26.2	16.4	41.1	25.4	118.4
Waterland en Droogmakerijen	50.2	77.7	39.1	56.5	28.1	16.4	41.1	20.5	118.4
Hollands/Utrechts weidegebied	45.1	69.7	34.0	49.1	26.0	16.0	39.7	27.1	114.1
Rivierengebied	46.5	71.7	36.1	52.3	26.9	14.6	36.4	22.6	114.1
Zuidwestelijk akkerbouwgebied	49.7	76.3	41.0	59.0	25.4	15.8	38.6	19.2	109.0
Zuidwest Brabant	44.5	68.5	36.0	51.9	26.6	15.5	38.0	20.8	109.0
Zuidelijk veehouderijgebied	39.8	61.6	29.9	43.4	27.8	16.4	40.4	22.8	110.6
Zuid-Limburg	44.2	68.5	37.0	53.7	26.4	15.9	39.2	22.7	110.6

As to their order of magnitude, the amounts and tendencies calculated by the model are confirmed by the literature. Van Hove (1969) reported that in Belgium soil organic matter content in meadows is about twice as high as that in arable fields (46 $g_{o.m.}$ kg^{-1} vs. 27 $g_{o.m.}$ kg^{-1}). Assuming a mass of the topsoil of $3{\cdot}10^6$ kg ha^{-1}, the carbon contents in the soil organic matter reported by Van Hove (1969) amount to 47 t_C ha^{-1} for arable land and 80 t_C ha^{-1} for grassland. It should be noted that in Table 4.2 the total carbon content of the crop-soil system is given. The calculated carbon content in the stable soil organic matter fraction is 2 – 6 t_C ha^{-1} lower.

Table 4.3. Average temperature data from five Dutch weather stations during 1961-1990. Source: Centraal Bureau voor de Statistiek, 1998a.

weather station	average air temperature (°C)	annual temperature amplitude (°C)
Eelde (NE)	8.6	14.6
De Kooij (NW)	9.5	13.5
De Bilt (central)	9.5	14.6
Vlissingen (SW)	10.1	13.7
Beek (SE)	9.6	15.2

Table 4.4. Steady state carbon pools in the crop-soil system in agricultural soils in the Netherlands. Areas are taken from Centraal Bureau voor de Statistiek (1998b) and relate to 1998.

	carbon content per ha (t_C ha^{-1}) in 0 – 30 cm	area (ha)	total carbon content (Mt_C)	
arable crops				
winter wheat	60.8	128,276	7.8	C content calculated by model
other winter cereals	60.8	3,075	0.2	C content equal to winter wheat
summer barley	46.1	36,658	1.7	C content calculated by model
other summer cereals	46.1	23,863	1.1	C content equal to summer barley
potato	26.6	181,302	4.8	C content calculated by model
sugar beet	27.9	114,190	3.2	C content calculated by model, area includes fodder beet
silage maize	22.0	239,399	5.3	C content calculated by model, area includes sweet maize and corn cob mix
pulses	9.3	8,454	0.1	C content derived from data by CBL (1980)
onions	4.2	18,349	0.1	C content derived from data by CBL (1980)
other arable crops	36.7	28,094	1.0	C content estimated as the average of other crops
fallow	36.7	12,371	0.5	C content estimated as the average of arable crops (Van Hove, 1969)
grassland	114.1	1,060,189	121.0	C content calculated by model, area includes temporary grassland and grass seed growing
horticultural crops	14.5	115,840	1.7	C content from Wolf & Janssen (1991b)
fast-growing wood	52.0	2,698	0.1	C content from Wolf & Janssen (1991a)
total		1,972,758	148.5	

Van der Sluys (1981) reported that the soil organic matter content in the topsoil of sandy soils increases from 34-37 g kg^{-1} in the south to 67-72 g kg^{-1} in the north. The trend is similar, but the difference is larger than in the model calculations. Janssen (1992) argues that the observed difference is caused by both an effect of temperature, which is lower in the north, and a precipitation deficit in summer, which is higher in the south. An effect of the soil water content on the rate of decomposition of soil organic matter is not included in the model calculations. Another reason for the larger difference may be that the data reported by Van der Sluys (1981) relate to sandy soils that warm up easily, while in the calculations average daily air temperatures at 1.5 m are used. It is also probable that, apart from biophysical processes, historical regional developments may have affected the differences. Assuming a mass of the topsoil of $3 \cdot 10^6$ kg ha^{-1}, the carbon contents reported by Van der Sluys (1981) range from 59 t_C ha^{-1} to 125 t_C ha^{-1}, while in this study the carbon contents that were calculated for arable fields range from 19 t_C ha^{-1} in silage maize to 82 t_C ha^{-1} in winter wheat. The difference may be attributed to the fraction inert soil carbon (Wolf & Janssen, 1991a; Janssen, 1992), which has a very long residence time in the soil, and is assumed not to be affected by the processes and on the time scale that is focussed on in this study.

Based on the average steady state carbon pools of different crops in the Netherlands, the total steady state (non-inert) carbon content of Dutch agricultural soils may be estimated (Table 4.4). From Table 4.4 it appears that by far the most carbon in Dutch agricultural soils (81%) is contained by grassland.

4.5 Fluxes

Monthly fluxes were calculated for the steady state of the carbon pool, using average yields for the Netherlands, and weather data from De Bilt in the centre of the Netherlands (Table 4.5).

Table 4.5. *Monthly net fluxes of carbon 'as the atmosphere sees it'.*

	winter wheat (t_C ha^{-1})		summer barley (t_C ha^{-1})		potato (t_C ha^{-1})	sugar beet (t_C ha^{-1})		silage maize (t_C ha^{-1})	grassland (t_C ha^{-1})	total agricultural area (Mt_C)
Opt	*1*	*2*	*1*	*2*		*1*	*2*			
Jan	0.44	0.34	0.31	0.24	0.40	0.71	0.68	0.50	0.63	1.09
Feb	0.40	0.30	0.28	0.22	0.36	0.64	0.60	0.45	0.59	1.01
Mar	0.45	0.35	0.31	0.25	0.41	0.72	0.69	0.51	0.72	1.20
Apr	-1.22	-1.30	0.32	0.27	0.42	0.71	0.72	0.50	-0.63	-0.53
May	-1.28	-1.34	0.36	0.33	0.46	0.75	0.81	0.54	-0.61	-0.48
Jun	-1.20	-1.23	-2.06	-2.08	-0.48	-0.90	-0.83	-0.35	-0.26	-1.04
Jul	-1.21	-1.23	-2.19	-2.20	-1.48	-1.00	-0.98	-1.28	-0.23	-1.49
Aug	1.31	1.81	0.98	1.31	-1.51	-1.02	-1.06	-1.29	-0.34	-0.78
Sept	0.80	0.93	0.60	0.69	-0.21	-1.00	-1.09	-1.27	-0.50	-0.85
Oct	0.59	0.58	0.43	0.42	0.72	-1.05	-1.17	0.61	-0.69	-0.45
Nov	0.48	0.41	0.34	0.30	0.49	0.70	0.88	0.54	0.70	1.22
Dec	0.45	0.36	0.32	0.26	0.43	0.73	0.76	0.52	0.65	1.14
Total	0.01	0.98	0.0	1.01	0.01	-0.01	1.01	-0.02	0.03	0.04

In steady state conditions annual fluxes are zero. Annual fluxes may be non-zero when the land cover changes, since the carbon pool will slowly approach a new steady state. Annual fluxes will also be non-zero since the weather conditions fluctuate from year to year, but over a longer period, this will only be true if there is a change in the climate. The model is able to calculate these changes in the carbon pool when the initial value of the soil carbon content is known.

Major changes in land cover in agricultural areas during the last 30 years are the decrease of the area grown with cereals, the decrease of the area grassland and an increase in the area grown with silage maize. Assuming that a new steady state has been reached, it was calculated that these changes in land cover have resulted in a loss of roughly 20 Mt_C from agricultural soils in the Netherlands between 1970 and 2000 (i.e. 2.4 Mt CO_2 on the average per year). It should be noted that possible changes in crop yields in this period are not included in the calculation.

4.6 Conclusions

Regional differences in yield and decomposition rate have a distinct effect on the carbon sequestering potential of agricultural land use in the Netherlands. Although yields (C input) in the north tend to be lower than in the rest of the country, the model calculates that the carbon content in the northern soils are higher as a result of the lower decomposition rates. Throughout the country grasslands have significant higher carbon sequestering potential than other land use. Whether agricultural areas are net sinks or niet sources of carbon is of minor importance for the assessment of the effects of carbon dioxide mitigation options, since a measure may reach its effect by the enhancement of a sink as well as reduction of a source.

5 Conclusions and recommendations

Three databases and approaches are options to assess soil carbon stocks:

- Based on the topographic soil map coupled with the soils information system;
- Based on the Netherlands soil monitoring program
- Based on the monitoring soils in forest and nature ecosystem.

The second option seems to be the best one. But even for this option the accuracy is maximal 80 percent. The total C stock in the top layer (0-30 cm) is calculated at 286 Tg C. The C stock under grassland is 148 Tg C, on arable land 85Tg C and in forest and nature is 31 Tg C. An other problem is that model underestimate the land uses areas. E.g. the areas for agricultural grass and arable land estimated by statistics in the Netherlands are about 28.5% and 17.6% smaller than calculated on the basis of the land use maps.

The pool of organic matter in the humus layer and in mineral soil of forest is estimated too. To do this the average value of the humus layer and the mineral soil is multiplied for several combinations with the soil areas for wood and nature. This was only possible for half of the total forested area and resulted in an estimation of a C content of 33.7 Mton for the total forests.

In the Dutch literature there is a wide range in the annual CO_2 emissions from the low wet areas in the western part: 0.1 to 7.0 ton C/ha. One of the elements of uncertainty is the exact size of the total area and of the amount of peat present. A map with thickness of peat layers would be helpful but does not exist. The estimates on peatland area range from 294.000 ha to 450.000 ha. In the Netherlands no database or map with thickness of peat layers is available (Rienks et al., 2002). The annual CO_2 emission from peat soils in the Netherlands on the basis of data on surface level changes is calculated at 1.3 – 1.9 Mton C per hectare per year or 4.8 – 7.0 Mton CO_2 per year.

On the basis of CESAR calculations it is clear that regional differences in yield and decomposition rate have a distinct effect on the carbon sequestering potential of agricultural land use in the Netherlands. Although yields (C input) in the north tend to be lower than in the rest of the country, the model calculates that the carbon content in the northern soils are higher as a result of the lower decomposition rates. Throughout the country grasslands have significant higher carbon sequestering potential than other land use. Whether agricultural areas are net sinks or niet sources of carbon is of minor importance for the assessment of the effects of carbon dioxide mitigation options, since a measure may reach its effect by the enhancement of a sink as well as reduction of a source.

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Appendix 1 Operational monitoring networks in the Netherlands

In the Netherlands, several other monitoring networks are operational and include:

- National Monitoring Network Soil Quality at RIVM in Bilthoven. The network design is a 5 year rotating scheme of a total of 200 land use Analyses (Soil): Soil chemical analyses include pH, lutum, organic matter and CEC and several chemical parameters in both soil and water.
- National Monitoring Network for Effects of N and P Policies at RIVM in Bilthoven. The network design is a rotating scheme with 81 plots sampled per year and these plots are stratefied by farming type and soil group. Chemical analyses include pH, EC, nitrate and several minerals.
- National Monitoring Network Groundwater Quality at RIVM in Bilthoven. The network is fixed with 400 locations and wells of 10/15/25 m depth. The chemical analyses in water include pH, temperature, redox-potential, EC, O2, HCO3 on site and extensive chemical analyses of soil water in the laboratorium.

Appendix 2 Info for table 5d

grassland (BAU)		C Fluxes (t C ha-1)				Total fluxes in Tg C (10E12g)			
	area [ha]	Min [tC/ha]	Max [tC/ha]	Mean [tC/ha]	Stdev	Total flux (min)	Total flux (max)	Total flux (mean)	Total flux (SD)
Netherlands	1.47E+06	-0.4607	1.6031	0.5642	0.7047	-0.68	2.36	0.83	1.04
EU_15	**4.93E+07**	**-1.8089**	**2.3110**	**0.6006**	**0.6473**	**-89.18**	**113.93**	**29.61**	**31.91**
arable (BAU)									
Netherlands	1.49E+06	-2.5483	-0.2247	-1.4131	0.6737	-3.80	-0.33	-2.11	1.00
EU_15	**9.31E+07**	**-2.9333**	**0.3059**	**-0.8327**	**0.4019**	**-273.09**	**28.48**	**-77.52**	**37.41**
Mitigation options - applied to all arable area (Vleeshouwers & Verhagen, 2002)									
conversion arable to grass	*9.31E+07*	*0.6305*	*3.0633*	*1.9180*	*0.5660*	*58.70*	*285.19*	*178.57*	52.69
notill	*9.31E+07*	*0.0000*	*717906.0000*	*0.2868*	*0.0882*	*0.00*	*66837048.60*	*26.70*	8.21
straw	*9.31E+07*	*-0.3060*	*0.3005*	*0.2133*	*0.0770*	*-28.48*	*27.97*	*19.86*	7.16
FYM	*9.31E+07*	*-0.6915*	*3.2060*	*1.4655*	*0.4468*	*-64.38*	*298.47*	*136.44*	41.59
co2	*9.31E+07*	*0.0034*	*0.0133*	*0.0101*	*0.0028*	*0.32*	*1.24*	*0.94*	0.26
temp	*9.31E+07*	*-0.1571*	*-0.0234*	*-0.0624*	*0.0193*	*-14.63*	*-2.18*	*-5.81*	1.80
All area	**1.42E+08**				**Yearly C flux**	**Total arable plus grass (min)**		**-362.27 Tg**	
					Yearly C flux	**Total arable plus grass (max)**		**142.42 Tg**	
					Yearly C flux	**Total arable plus grass (mean)**		**-47.91 Tg**	
					Yearly C flux	**Total arable plus grass (SD minimum)**		**37.41 Tg**	

TABLE 5.D SECTORAL BACKGROUND DATA FOR LAND-USE CHANGE AND FORESTRY
CO_2 Emissions and Removals from Soil
(Sheet 1 of 1)

GREENHOUSE GAS SOURCE AND SINK CATEGORIES	ACTIVITY DATA	IMPLIED EMISSION FACTORS	ESTIMATES
	Land area (Mha)	Average annual rate of soil carbon uptake/removal (Mg C/ha/yr)	Net change in soil carbon in mineral soils (Tg C over 20 yr)
Cultivation of Mineral Soils [(1)]			**0.00**
High Activity Soils		0.00	
Low Activity Soils		0.00	
Sandy		0.00	
Volcanic		0.00	
Wetland (Aquic)		0.00	
Other *(please specify)*			0.00
		0.00	
	Land area (ha)	Annual loss rate (Mg C/ha/yr)	Carbon emissions from organic soils (Mg C/yr)
Cultivation of Organic Soils			**0.00**
Cool Temperate			**0.00**
Upland Crops		0.00	
Pasture/Forest		0.00	
Warm Temperate			**0.00**
Upland Crops		0.00	
Pasture/Forest		0.00	
Tropical			**0.00**
Upland Crops		0.00	
Pasture/Forest		0.00	
	Total annual amount of lime (Mg)	Carbon conversion factor	Carbon emissions from liming (Mg C)
Liming of Agricultural Soils			**0.00**
Limestone $Ca(CO_3)$		0.00	
Dolomite $CaMg(CO_3)_2$		0.00	

Total annual net carbon emissions from agriculturally impacted soils (Gg C)	NE
Total annual net CO_2 emissions from agriculturally impacted soils (Gg CO_2)	NE

Additional information

Year	Climate [(a)]	land-use/ management system [(a)]	Soil type: High activity soils	Soil type: Low activity soils	Soil type: Sandy	Soil type: Volcanic
			percent distribution (%			
20 years prior	*(e.g. tropical, dry)*	*(e.g. savanna)*				
		(e.g. irrigated cropping)				
inventory year						

[(a)] These should represent the major types of land management systems per climate regions presented in the country as well as ecosystem types which were either converted to agriculture (e.g., savanna, grassland) or have been derived from previous agricultural land-use (e.g., abandoned lands reforested lands). Systems should also reflect differences in soil carbon stocks that can be related to differences in management (IPCC Guidelines (Volume 2. Workbook, Table 5-9, p. 5.26, and Apper (pp. 5-31 - 5.38)).

[(1)] The information to be reported under Culitvation of Mineral Soils aggregates data per soil type over all land-use/management systems. This refers to land area data and to the emission estimates and implied emissions factors accordingly.

Note: Sectoral background data tables on Land-Use Change and Forestry should be filled in only by Parties using the IPCC default methodology. Parties that use country specific methods and models should report information on them in a transparent manner, also providing suggestions for a possible sectoral background data table suitable for their calculation method.

Documentation Box: