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EMISSIONS AND METHODOLOGIES FOR CROPLAND AND GRASSLAND USED IN THE NORWEGIAN NATIONAL GREENHOUSE GAS INVENTORY

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PREFACE

The Norwegian Forest and Landscape Institute (NFLI) annually carries out the national greenhouse gas (GHG) inventory for the land use, land-use change and forestry (LULUCF) sector as part of the National Inventory Report (NIR). The NIR is submitted to the secretariat for the United Nations Framework Convention on Climate Change (UNFCCC). The present report provides a comprehensive documentation of new methodologies used in the reporting of CO_2 emissions and removals from cropland and grassland, implemented in the 2013 NIR. Furthermore, the report includes evaluations of the previously used methods. This supplementary documentation may be helpful to UN reviewers of the NIR as well as other LULUCF inventory compilers in other countries or anyone interested in the methodologies used in the national reporting. We thank Arnold H. Arnoldussen, the head of section Soil Resources at NFLI, and Gunnhild Søgaard, the head of section Climate Center at NFLI, for valuable comments during the preparation of this report. Also, we would like to acknowledge Lise Dalsgaard, Johannes Breidenbach, and Rune Eriksen for their work contributing to the area, emission, and uncertainty estimates reported by the NFLI as part of the Norwegian NIR.

ABSTRACT

Every year the Norwegian Forest and Landscape Institute submits the national GHG inventory for the land use, land-use change and forestry sector as part of the National Inventory Report (NIR). The methodology and activity data used to estimate CO_2 emissions and removals from cropland and grassland were thoroughly evaluated in 2012 and several new methods were implemented in the 2013 NIR submission. The objective of this report is to present the results of this evaluation and to provide detailed documentation of the new methodologies and the emissions reported in the 2013 NIR submission to UNFCCC for cropland and grassland (CPA, 2013).

This report describes four major topics:

1) Method choice for mineral soils. The erosion-based method previously used for mineral soils on both cropland and grassland cannot be considered appropriate. It was replaced by a Tier 2 method for cropland remaining cropland (considering effects of crop rotation, tillage, crop residues and manure inputs) and a Tier 1 method for grassland remaining grassland (considering effects of grassland management practice).

2) Evaluation of the emission factor used for organic soil and the area estimate. A review of Scandinavian literature did not support changing the emission factor value but the areas of cultivated organic soils were re-defined under cropland and grassland.

3) A Tier 1 methodology that can be used to estimate soil carbon stock changes on land-use conversion to grassland and cropland as well as all other land-use change conversion.

4) Uncertainty estimation for all source/sink categories are presented including the use of IPCC default uncertainty estimates when relevant.

SAMMENDRAG

Norsk institutt for skog og landskap har ansvar for å beregne årlige utslipp og opptak av klimagasser som skyldes jordbruk, skog, skogbruk og arealbruksendringer. Arealbruken er definert i seks klasser som følger internasjonale definisjoner: skog, dyrket jord, beitemark, vann og våtmarksområder, bebygde- og andre arealer (e.g. snaumark og fjellområder). Beregningene følger internasjonale regler som er utarbeidet av FNs klimapanel (IPCC). Detaljerte beskrivelser av datagrunnlaget og metoder for beregningene inngår i den nasjonale rapporten som sendes hvert år til sekretariatet for FNs klimakonvensjon (United Nations Framework Convention on Climate Change - UNFCCC).

I 2012 ble datagrunnlaget og metoder som ble brukt til å beregne utslipp og opptak av CO_2 fra dyrket jord og beitemark evaluert. Med bakgrunn i dette arbeidet ble nye datasett og nye metoder for beregninger brukt i den nasjonale rapporteringen i 2013 (CPA, 2013). Målet med denne rapporten er å presentere resultatene fra evalueringen og gi en detaljert beskrivelse av dataene, de nye metodene og resultatene for perioden 1990-2011.

Rapporten beskriver fire hovedpunkter for dyrket jord og beitemark:

1) Metodevalg for mineraljord. Den erosjonsbaserte metoden som tidligere ble brukt til å beregne endringer i karbon i mineraljord for dyrket jord og beitemarker er ikke hensiktsmessig. For dyrket jord som er kontinuerlig under dyrking, ble den tidligere metoden erstattet med en Tier 2 metode. Metoden tar hensyn til effekten av rotasjon av vekster, jordbearbeiding, nedbryting av planterester og husdyrgjødsel. For beitearealer ble en Tier 1 metode som tar hensyn til forskjellige behandlinger brukt.

2) Evaluering av arealet av og utslippsfaktor for organisk jord. Arealet ble revidert. Et litteraturstudium av utslippsfaktorer som er brukt for organisk jord i Skandinavia ga ikke grunnlag for å endre faktoren som er brukt i tidligere beregninger.

3) Beskrivelser av Tier 1 metoden som er brukt til å estimere endringer i jordkarbon for arealoverganger til dyrket jord og beitemark og for alle andre mulige arealbruksoverganger.

4) Metoder for beregning av usikkerhetsestimater for de kategoriene som forårsaker utslipp av klimagasser eller lagring av karbon. Nasjonale metoder og IPCC sine standardiserte metoder er brukt til å beregne usikkerheten i utslipps- og karbonlagerestimatene.

Nøkkelord:	Klimagassutslipp, jordbruk, beite, grasarealer, arealbruksendringer, endringer i jordens organiske karbonlager, usikkerhetsestimater, det nasjonale klimagassregnskap .
Key words:	Greenhouse gas emissions, cropland, grassland, land-use change, soil organic carbon changes, uncertainty estimates, national inventory report.
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CONTENT

1. INTRODUCTION

1.1. National greenhouse gas inventory reporting

The national greenhouse gas (GHG) inventory reported to the United Nations Framework Convention on Climate Change (UNFCCC) includes a National Inventory Report (NIR) and the Common Reporting Format (CRF) where all emissions are reported. Since 1994, nations have accounted for GHG emissions and annual NIR submissions are available on the UNFCCC website from 2008 and onwards. Reporting under the convention has been made annually and emissions are inventoried for each year from 1990 and onwards with the last year of the inventory period being two years prior to the submission year (thus, the 2013 submission covers the inventory period from 1990 to 2011). The national inventories include the following six sectors: 1) energy, 2) industrial processes, 3) solvent and other product use, 4) agriculture 5) land use, land-use change and forestry (LULUCF), and 6) waste. In addition, Norway is also obliged to provide supplementary information, which is required under Article 7, paragraph 1, of the Kyoto Protocol by all Annex I Kyoto Protocol Parties. A separate reporting for the period 2008-2012 is made for the so-called Article 3 activities, which for Norway are afforestation, deforestation (Article 3.3 activities) and forest management (Article 3.4 activities). Other countries may also have selected cropland or/and grazing land management as Article 3.4 activities. This reporting is referred to as KP-LULUCF. The Norwegian Forest and Landscape Institute (NFLI) is responsible for delivery of the emission estimates and the documentation related to reporting of LULUCF and KP-LULUCF to the Norwegian Climate and Pollution Agency who compile the final submissions to the UNFCCC.

The LULUCF sector is divided into six major land-use categories: forest land, cropland, grassland, wetlands, settlement and other land. This report focuses on the methods and emission under cropland and grassland and land-use conversions to cropland or grassland.

1.2. IPCC methodology for reporting of greenhouse gas emissions

To enable uniform and accurate estimates of greenhouse gas emissions by all member states regardless of national availability of activity data or other capacities, the Intergovernmental Panel for Climate Change (IPCC) have developed methodologies. The first methodologies for LULUCF were produced in 1996 in the Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories with the Reference Manual (Volume 3) for Land Use Change and Forestry (IPCC, 1997). In 2003, the IPCC Good Practice Guidance was released with Chapter 3 pertaining specifically to land use change and forestry (IPCC, 2003b). Currently, the mandatory requirement is to follow these guidelines.

In 2006, IPCC released an updated version of the reporting guidelines, which was the result of a larger international scientific voluntary collaboration. In the 17^{th} UNFCCC conference of parties (COP 17), it was decided that all nations should use the 2006 IPCC Guidelines for National Greenhouse Gas Inventories starting from the 2015 submission with the beginning of the second commitment period. The 2006 guidelines provides an updated, information-rich, and comprehensible version of the IPCC Guidelines for greenhouse gas reporting that fulfills well the purpose of facilitating inventory compilers during the reporting process. Compared to the Good Practice Guidance of 2003, the methodological instructions described in the 2006 guidelines are more detailed. The methodologies presented in this report comply with both the 2003 and the 2006 guidelines.

IPCC have provided methodologies at three tier levels for all source categories (see Box 1 for overview). Tier 1 is the default method with emission or stock change factors listed in the guidelines. Tier 2 uses the same calculation methods but make use of national or country-representative data in the derivation of emission or stock change factors. Tier 3 methods use dynamic modeling and/or are based on extensive measurements. Thus, as the tier level increase so does the complexity of the model and the requirements to the activity data.

Box 1: IPCC methods of three tiers for calculating soil C stock changes

Tier 1
Standard equations using default stock change factors and soil C reference stocks.

Tier 2
Standard equations using country-specific stock change factors and soil C reference stocks. Reference conditions and time dependency of stock change factors can be adjusted.

Tier 3
Calculations based on modeled or measured C stock changes or a combination of the two.

IPCC have developed methods for both CO_2 emissions and non-CO_2 emission (CH_4 and N_2O, which are not included in this report). CO_2 emissions are based on estimates of carbon (C) stock change in three major pools (living biomass, dead organic matter and soils) multiplied with 44/12 the stoichiometric conversion of carbon (C) to CO_2. The 2006 guidelines include dead organic matter as a new source category on Tier 2 and 3 levels compared to guidelines of 2003. Dead organic matter (DOM) includes the two pools of dead wood and litter. In general, cropland systems may have little dead wood, crop residues or litter, with the exception or agroforestry and orchard systems. The Tier 1 assumption is that DOM is in equilibrium in all cropland systems. For Tier 2 or 3 approaches, nations may use either the gain-loss or the stock-difference method to estimate changes in the C pool of DOM. For Norway, the Tier 1 assumption may suffice given relatively small areas of fruit trees and thus small potential C stocks and changes in this pool and C stock changes in DOM is reported as not occurring for cropland remaining cropland and grassland remaining grassland. However, forest land converted to cropland or grassland may have non-negligible amounts of C in litter and dead wood stocks. A Tier 2 method is presented for DOM in the land-use conversions chapter, which was used in the 2013 NIR submission.

1.3. Land-use changes reported in the Norwegian inventory

In order to provide the national GHG estimates caused by land use and land-use changes, land-cover data for the whole country is needed. Data collected in the National Forest Inventory (NFI) provide area estimates of all land-use categories as well as the changes between them. Areas are equal to the sum of representation factors of all sample plots of a full NFI cycle (5 years) belonging to the same land-use class (CPA, 2013). In addition, the NFI also records the biomass stock of trees and many other variables, especially for plots classified as forest. Between the 2012 and 2013 NIR submission, the NFI database was quality checked to ensure that a consistent time-series of areas (and living biomass) estimates exist for all plots. The revision of the database also included quality control of land-use changes.

From 1990 and onwards, relatively small changes have occurred in the overall land use. The most noticeable change was an increase in the areas of settlements (Figure 1).

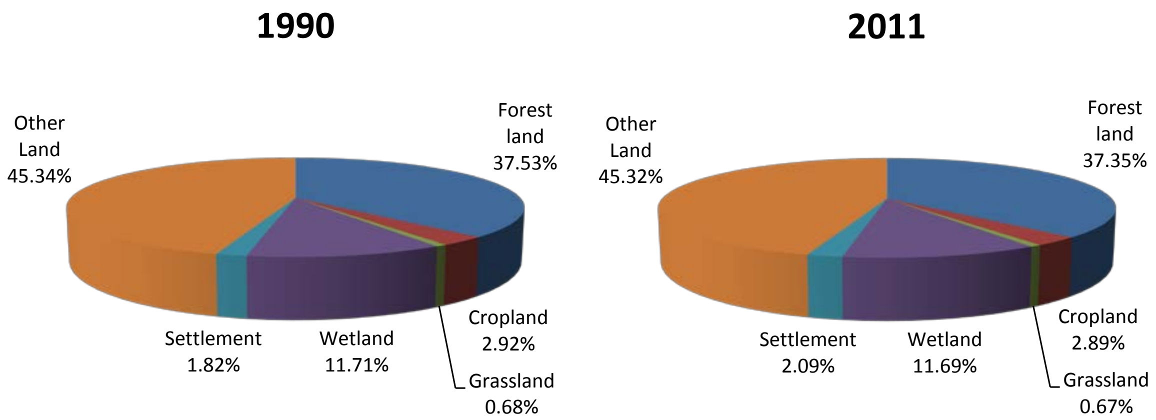

Figure 1: Land-use changes observed between 1990 and 2011 in Norway. Source (CPA, 2013).

Both cropland and grassland areas have decreased slightly since 1990. The cropland area reduced from 2.92% to 2.89% of the total Norwegian land area and grassland from 0.68% to 0.67%. However, the uncertainties in the area estimates are relatively large for the land-use conversions (around ±40%; see chapter 5). It is therefore not certain that actual changes in land use have occurred.

Under the UNFCCC reporting framework, emissions are reported separately for areas of land that have remained in the same land-use category for the whole inventory period and areas that have changed land-use category. Areas that have changed must be accounted for in the conversion category for 20 years before it can be considered in the remaining category. For the 1990-2011 inventory period, the following areas were determined: cropland remaining cropland of 919 242 ha, land converted to cropland of 17 233 ha, grassland remaining grassland of 196 770 ha, and land converted to grassland of 19 587 (Table 1). The largest areas of land converted to cropland or grassland comes from forest land. These areas are important in the KP-LULUCF accounting under deforestation activities. No land was converted from other land, which includes waste land, areas with bare rocks or shallow soils, or unfavorable climatic conditions.

Table 1: Areas (ha) of cropland and grassland in 2011. Source: (CPA, 2013).

	From 1990 to 2011	
Land-use category	Cropland	Grassland
Forest land	11 666	19 046
Cropland	919 242	0
Grassland	1 702	196 770
Wetland	3 064	541
Settlements	801	0
Other land	0	0
Land converted to cropland or grassland	17 233	19 587
Land remaining as cropland or grassland	919 242	196 770
Total cropland or grassland in 2011	936 475	216 357

Agricultural land (croplands and grasslands) that have been abandoned are reported under the land-use category that the land is converted to. The NFI database records show that cropland has primarily been converted to settlements (15 001 ha) and to forest (9 884 ha). Grassland was mostly converted to forest (15 551 ha), but also to settlements (4 406 ha), other land (2 604 ha), and cropland (1 702 ha). The soil C stock changes on abandoned cropland or grasslands were estimated using the same method described in this report for land-use conversion (chapter 4.2).

1.4. Objectives

The objective of this report is to provide detailed description and documentation of the methodologies used in the 2013 NIR submission for the cropland and grassland land-use categories and to give an overview of the estimated emissions reported for the inventory period 1990-2011 (CPA, 2013). Until last year, the methods used in the Norwegian inventory reporting were as described in a report from 2005 (NIJOS, 2005). These methods were evaluated in 2012 through a quality assurance project performed by an external qualified person elicited by the NFLI. The project entailed an evaluation of the compliance of the methodologies used in the 2012 NIR with the IPCC guidelines and other scientific literature as well as quality checking of the values reported in the CRF (Common Reporting Format) tables. This document reports on the methodological changes identified as necessary and provides the supplementary documentation potentially needed by UN reviewers of the inventory report and other interested persons.

This report is outlined by five chapters: 1) croplands, 2) grasslands, 3) land-use conversions to cropland or grassland, and 4) uncertainty estimation, and 5) conclusion. The first two chapters deal with the methodologies and emissions estimated for areas remaining under the same land-use class. As the methodology is the same for emission estimates for land converted to cropland or grassland, these are described in the same chapter. According to the IPCC guidance, it is mandatory to provide uncertainty assessments of emission estimates as part of the NIR in order to identify key categories with large emissions and /or uncertainty (IPCC, 2003c). This is the reason for the inclusion of the fourth chapter on uncertainty assessment.

2. CROPLANDS

Croplands cover almost 3% of the Norwegian land area. In the NFI, cropland is defined as annually cropped land where soils are regularly cultivated and plowed. This is in accordance with the IPCC guidelines (IPCC, 2003a; 2006c). Grass leys in rotation with other crops are also classified as cropland and are not considered grasslands. In previous NIR reports, the term meadow was used for grass leys in rotation (in Norwegian *eng*), but this could be misunderstood and interpreted as meadows commonly refer to as unmanaged natural heath land.

Compared to the NIR 2012, major changes were made in the methods used for the emission estimation under cropland in the 2013 inventory report. For living biomass the activity data was updated and assumptions of land use transition modified. Perennial berry bushes were considered to be included in the inventory, but the area is relatively small and inclusion in the reporting could not be warranted. A new Tier 2 method is proposed for estimation of emissions from mineral soils and the activity data was updated and stratified regionally. The method considers country-specific interactions of soils, climate and management factors, however, it implies substantial assumptions. Emission factors and activity data for organic soils (histosols) were evaluated and the assumption of the area of cultivated histosols under cropland or grassland was changed.

2.1. Living biomass

Living biomass on cropland is reported for orchard crops only, i.e. fruit trees. Fruit cultivation is not a major production system in Norway and has covered an area between 2000-3000 ha, declining over the past 20 year. The vast majority of the fruit trees (approximately 47%) is produced in Hordaland county and the second largest proportion (approximately 19%) in Sogn og Fjordane county. Given the general desire to elevate the Tier level and the large uncertainties of the default method that is currently used in the inventory, we present an alternative method based on measurements in Denmark.

2.1.1. METHODOLOGY

The Tier 1 default method is used to estimate changes in C stocks in living biomass. In the default method the change in C stock in living biomass (ΔC_{LB}) is the sum of C gain (ΔC_G) and C loss (ΔC_L) and calculated as:

$$\Delta C_{LB} = \Delta C_G + \Delta C_L$$ Equation 2.4 (IPCC, 2006a).

Two main assumptions are implied in the Tier 1 methodology: 1) that C accumulates for a finite period (default value is 30 years) until the trees have reached maturity or are harvested, and 2) that all C biomass is removed at harvest. Only aboveground biomass is considered.

2.1.1.1. Emission/removal factors

The default values provided for ΔC_G and ΔC_L for temperate climate are 2.1 Mg C ha^{-1} yr^{-1} and 63 Mg C ha^{-1}, respectively (IPCC, 2006b). As a reference IPCC cites a literature review by Schroeder (1994), which gives literature on agroforestry systems in the sub-tropics and tropics, but for temperate climatic conditions, the study(ies) producing the above-mentioned estimates are not mentioned by Schroeder. This makes it difficult to evaluate the foundation of the estimates and compare with Norwegian conditions. In addition, there are relatively large uncertainties connected with the default values.

2.1.1.2. Data

In previous inventory reports it was assumed that when orchard trees were felled, grassland would replace the vegetation (NIJOS, 2005). This assumption was reconsidered due to the fluctuations in the orchard area. We find it equally likely that the lands of terminated orchards would enter a crop rotation with grass leys, cereals, root crops or other vegetables. Thus, the C losses previously reported under land converted to grasslands, sub-category horticulture (5C2) are now accounted for under cropland remaining cropland (5B1). Quantitatively, in terms of emissions/removals it makes no difference when total emissions from grassland and cropland are summed.

The area data were collected by the Norwegian Agricultural Authority (NAA) through the agricultural subsidy application scheme, and compiled by Statistics Norway (SSB). In previous NIRs, the areas were modified due to a change in the sampling method. But to increase the transparency of the activity data, it was not done in the 2013 NIR and the unmodified areas were used. Reported emissions/removals for living biomass under cropland remaining cropland in the 2013 NIR were slightly different from those reported in 2012 due to the adjustment in the time series. The percent differences between the areas were largest (8%) from 2004 and onward (Table 2).

Table 2: Areas of orchards in Norway; the old modified, new unmodified areas (ha) and the% difference.

Year	Old modified area (ha)	New unmodified area (ha)	Difference (%)
1989	3267	3267	0%
1990	3214	3228	0%
1991	3162	3189	1%
1992	3109	3149	1%
1993	3056	3110	2%
1994	3003	3071	2%
1995	2950	3031	3%
1996	2897	2992	3%
1997	2844	2761	-3%
1998	2844	2693	-5%
1999	2791	2647	-5%
2000	2718	2650	-3%
2001	2611	2652	2%
2002	2593	2613	1%
2003	2385	2563	7%
2004	2359	2538	8%
2005	2305	2480	8%
2006	2227	2396	8%
2007	2244	2415	8%
2008	2315	2491	8%
2009	2345	2524	8%
2010	2023	2177	8%

2.1.1.3. Alternative method: Tier 2 with Danish C stock factors

In the absence of Norwegian data of C stocks or changes in fruit trees, we searched the scientific literature for (recent) studies from where to derive country-representative stock change factors. No peer-reviewed publications were available. However, in the supplementary documentation for the Danish GHG accounting of the LULUCF sector results were cited. Without reference to specific studies Gyldenkærne *et al.* (2005) provide estimates of C storage in aboveground biomass of horticultural crops such as apples, pears, plums, and cherries. In the Danish inventory, the C stocks per crop type are multiplied with the changes in the area according to a Tier 2 stock-difference method (NERI, 2011). This approach seems promising for Norway, due to the close climatic similarities of Norway with

Denmark (especially when looking at the areas in Norway which are suitable for fruit production) compared to the global default values provided by IPCC.

Annual emissions based on the Danish method were calculated assuming the following C contents in living biomass on areas with: apples 16.9 Mg C ha^{-1}; pears 7 Mg C ha^{-1}; plums and cherries 13 Mg C ha^{-1}. The resulting CO_2 emissions were positive using this stock-difference method giving a total loss of 17.4 Gg CO_2 for 1990-2010 (Table 3), whereas the gain-loss method with default IPCC emission factors yielded a total CO_2 uptake of 159.1 Gg CO_2 for the same period (emissions shown in Figure 2).

Table 3: Areas of individual fruit trees (apples, pears, plums, and cherries) and annual CO_2 emissions estimated by the Tier 2 stock-difference method using Danish C stock factors.

Year	**Area of fruit trees (ha)**				**CO_2 emissions (Gg C yr^{-1})**				
	Apples	Pears	Plums	Cherries	Apples	Pears	Plums	Cherries	Total
1990	2259	311	358	300	0.71	0.01	0.02	0.02	0.8
1991	2231	307	353	297	0.71	0.01	0.02	0.02	0.8
1992	2204	303	349	293	0.71	0.01	0.02	0.02	0.8
1993	2176	300	345	289	0.71	0.01	0.02	0.02	0.8
1994	2149	296	340	286	0.71	0.01	0.02	0.02	0.8
1995	2121	292	336	282	0.71	0.01	0.02	0.02	0.8
1996	2094	288	332	279	0.71	0.01	0.02	0.02	0.8
1997	1981	275	298	207	2.89	0.03	0.16	0.34	3.4
1998	1930	234	310	218	1.30	0.10	-0.06	-0.05	1.3
1999	1894	215	311	227	0.93	0.05	0.00	-0.04	0.9
2000	1859	202	320	268	0.89	0.03	-0.04	-0.19	0.7
2001	1825	190	328	310	0.89	0.03	-0.04	-0.19	0.7
2002	1794	177	330	312	0.79	0.03	-0.01	-0.01	0.8
2003	1764	162	343	294	0.77	0.04	-0.06	0.09	0.8
2004	1731	150	363	294	0.85	0.03	-0.09	0.00	0.8
2005	1695	138	370	278	0.93	0.03	-0.03	0.08	1.0
2006	1645	129	352	271	1.29	0.02	0.08	0.03	1.4
2007	1652	127	361	275	-0.20	0.00	-0.04	-0.02	-0.3
2008	1682	122	407	280	-0.76	0.01	-0.21	-0.03	-1.0
2009	1704	124	417	279	-0.55	0.00	-0.05	0.01	-0.6
2010	1428	90	416	243	7.08	0.09	0.01	0.17	7.3
Total emissions for 1990-2010					17.1	0.50	-0.40	0.20	17.4

2.1.1.4. Assumption: exclusion of perennial berry bushes

The IPCC guidelines states that perennial woody vegetation on cropland can be considered as potential sinks or sources of C emissions (IPCC, 2006b). Perennial berry bushes can be a sink of C emissions due to the potential of woody biomass that may built up. In Norway the area of berries bushes is almost as large as that with fruit trees. However, strawberries comprise the majority of the berries and the perennial berries, mostly black and red currants, cover a much smaller area of 331 ha in 2010 (Table 4). The area of raspberries is about the same size as black and red currants, however C storage in raspberries can be considered smaller than for currants. Most of the perennial berries (85% of the area) are cultivated in three counties (Telemark, Hedmark, and Buskerud).

Table 4: Areas of fruit trees, berries (strawberries, raspberries, blue berries, and currants), and individual berry types in 2010 (SSB, 2012).

	Area (ha)
Fruit trees	2039
Total berries	1956
Black and red currants	331
Raspberries	289
Strawberries	1337

Black currants can produce up to 6 Mg ha^{-1} yr^{-1} of woody dry matter (Detoro, 1994). A C increment of 3 Mg C ha^{-1} yr^{-1} could potentially influence the C budget of these systems, if 50% of the woody material is assumed to be carbon. However, black currants and similar berry bushes are normally trimmed annually and do not provide long-term C storage. CO_2 emissions over time would only be influenced if a significant change in the cultivated area occurred. If the area was to change substantially in the future, accounting and reporting in the inventory may be facilitated using Danish data of C storage (Gyldenkærne *et al.*, 2005) and the stock-difference method.

2.1.2. EMISSIONS AND REMOVALS FROM ORCHARDS

The estimated emissions from C stock change in living biomass in the fruit trees are relatively small (Figure 2). Emissions were high in 2010 due to the cutting down of almost 350 ha of fruit trees. That year the net C stock change of -17.2 Gg C (equal to 63.4 Gg CO_2) was the largest over the inventory period.

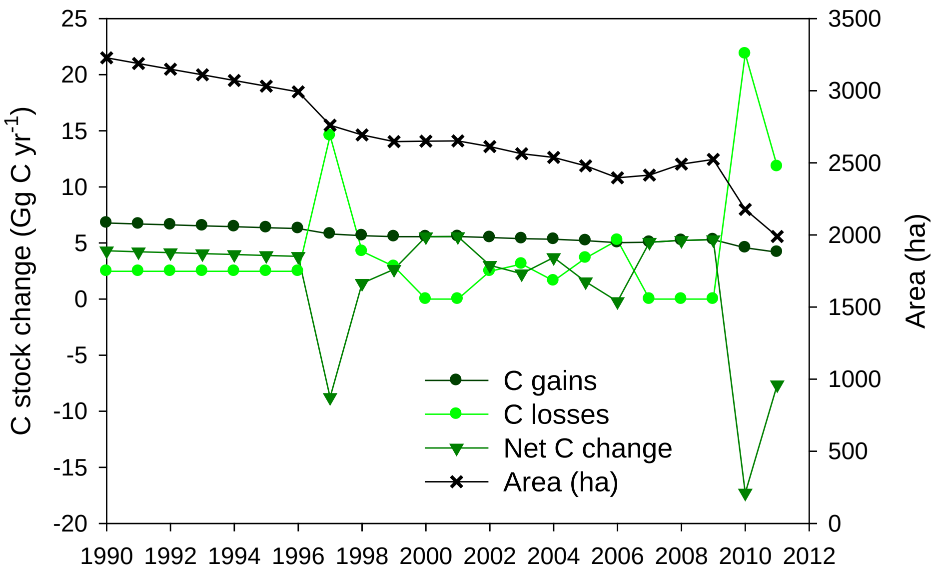

Figure 2: Carbon stock change in living biomass (gains, losses and net change) and the area of fruit trees in Norway from 1990 to 2011.

2.2. Mineral soils

This chapter presents an evaluation of the methodology that was used in the inventories up to 2012 (section 2.2.1), description of alternative methods of all Tier levels (section 2.2.2), and the emissions estimated with the Tier 2 method (section 2.2.2.4), which was chosen for the 2013 NIR.

2.2.1. EVALUATION OF THE OLD METHODOLOGY

2.2.1.1. Emission estimates based on soil erosion loss and spring or fall plowing

The methodology used previously to estimate CO_2 emissions from mineral soils on cropland was a modified Tier 2 approach (NIJOS, 2005). The Tier 2 was modified in the sense that it was not based on the default calculation approach using equation 2.25 (IPCC, 2006a) with country-specific values. Instead, the Norwegian method considered the effects of soil erosion on changes in soil organic carbon (SOC) stocks caused by agricultural management by multiplying a C loss rate specific to spring or fall plowing with the pertaining area. Accelerated soil erosion (due to agriculture) was estimated based on a study by Singh and Lal (2005), whose calculations also included different C losses for soil under spring or fall plowing regimes. Influences of crop rotation, plant residue incorporation and manure management were not accounted for. Regional impacts of climate and soil properties combined with agricultural management were ignored as well. Thus, a national soil C loss rate was assumed (due to erosion) based on spring or fall plowing time. The method raises two questions. First, do spring or fall plowing regimes produce different C mineralization rates? And second, does erosion on agricultural fields result in net C emissions?

It may be true that soil tillage in the spring rather than the fall reduces C mineralization. Borgen *et al.* (2012b) simulated annual CO_2 emissions to be less than half the amount under a spring-plowed clover-grass and grain rotation compared to a fall-plowed rotation in south-east Norway. The model indicated that the differences were caused by a difference in microbial respiration. However, theories on soil organic matter formation emphasize tillage frequency more than timing for C accumulation in soil (Paustian *et al.*, 2000; Six *et al.*, 1999). In the previous Norwegian Tier 2, spring-plowing was considered as reduced tillage and fall plowing as full (traditional) tillage, but strictly speaking there was no reduction in tillage frequency or plowing depth. The IPCC methodology does not differentiate between spring and fall plowing time, although this may have a significant influence under the climatic conditions in Norway. Reducing tillage intensity is assumed to lower CO_2 emissions because more aggregates can form under less frequent physical disturbance, which is incorporated in the IPCC Tier 1 methodology by a management stock change factor representing tillage frequency. However, when including the subsoil in the SOC stock measurements, it seems that reduced (or no-till) practices redistribute SOC deeper in the soil profile compared to full-inversion plowing.

2.2.1.2. Soil erosion – a sink or source of CO_2 emissions?

Several studies have concluded that erosion causes a net release of CO_2 and thereby deducing that erosion prevention would mitigate greenhouse gas emissions (Jacinthe and Lal, 2001; Lal, 2003; Lal *et al.*, 2004; Lal and Pimentel, 2008). Some of these studies are the foundation of the assumptions used in the old Norwegian Tier 2 method. However, other studies have shown that it is not always correct to assume that erosion induces C emissions on the field level. A field or region may have smaller individual areas where both net C emission and net C sequestration occurs. The relative contribution of the various mechanisms involved in the erosion process and their influence on the C budget will then determine the effect on the larger scale (Berhe *et al.*, 2007). For example, a field may have areas where C-rich topsoil with low bulk density and a high decomposition rate is removed at the eroded site, while exposing deeper soil layers with less SOC and potentially lower decomposition rates compared to adjacent non-eroded slopes (Berhe *et al.*, 2007). Such a situation would cause a site to go from a relatively high C loss rate to a relatively lower C loss rate.

Another phenomenon termed 'dynamic replacement' has also been mentioned. When plant residues are added at the eroded site, the lost carbon is relatively quickly replaced because net primary productivity continues and in some cases at an accelerated rate. This was hypothesized by Stallard (1998) and later measured by Harden *et al*. (1999) to significantly alter the C balance. If the increased C inputs at the eroded site are combined with reduced decomposition at the deposition site, the overall ecosystem usually functions as a sink of atmospheric CO_2 (Berhe *et al.*, 2007). There has been disagreement about the net effect of agricultural soil erosion on CO_2 emission in the scientific literature. Opposing opinions were debated in Science (Lal and Pimentel, 2008; Van Oost *et al.*, 2008; Harden *et al.*, 2008). Among other things, the controversy appears to be related to the scale of the study but also the mechanistic processes in focus.

2.2.1.3. Carbon mechanisms under erosional events

A realistic representation of how changes in C fluxes are affected throughout the entire ecosystem or watershed is necessary for an appropriate representation of erosional events. Carbon transformations during all steps of the erosion process should be considered. During an erosion event soil is: 1) detached at the eroded site, 2) transported by water or air, and 3) deposited on hill depressions or in rivers, lakes or other waterways. It is difficult to determine the fate of eroded C and changes in the soil C decomposition rate during detachment, transport, and deposition (Lal, 1995). Lal (2003) reviews a number of mechanisms that influence the C cycle during erosion, such as slacking and disruption of aggregates, preferential movement of C in run-off and dust storms, and altered mineralization rates of SOC at the eroded site and while soil is redistributed in the landscape. On the deposition site, organic matter decomposition rates may be reduced due to physical protection caused by deep burial, aggregate formation, or increased water content, and due to biochemical formation of organo-mineral compounds or organic substrates. For inventory purposes and carbon accounting, it is the net effect of the C flux changes of all mechanisms combined that is relevant.

2.2.1.4. Conflicting results

The magnitude of the net effect of soil erosion on the soil C balance may be small. In a study by Oost *et al.* (2007), isotopic 137Cs analyses of a large-scale dataset of 1400 soil profiles in 10 watersheds in Europe and USA led to the conclusion that soil erosion does not represent an important source of CO_2 emissions nor does it act as a sink on a global scale. Similarly, Manies *et al.* (2001) concluded for an agricultural site that the impacts of erosion on the CO_2 budget are likely to be highly heterogeneous in both space and time. Variability of the results was also emphasized by Harden *et al.* (1999) who summarize that erosion may induce unaccounted sinks or sources of CO_2, depending on the fate of eroded carbon and its protection from decomposition. Thus, these studies indicate that erosion may have little effect on the net C balance.

However, quite large effects on the C balance have also been found. For example, in a wetland downstream from an agricultural area in Maryland, USA, McCarty and Ritchie (2002) measured annual C sequestration rates in the range of 1.7-2.2 Mg C ha^{-1} yr^{-1}, which was 4-7 times larger than previous estimates made by Lal *et al.* (1998). Smith *et al.* (2001) conclude that the primary fate of eroded soil across conterminous USA was the trapping in impoundments. Furthermore, they concluded that the movement of soil from one reservoir with a fast turnover rate to another with a slower rate would alone grant C sequestration (even when ignoring the dynamic replacement effect). These studies illustrate examples where large C sequestration rates were measured at the watershed catchment level.

Other studies have illuminated the complexity in predicting soil C movement caused by erosion even on a smaller scale such as the field level. Measurements in Germany showed that rill erosion caused an enrichment of organic C in the sediment at a distance from the source erosion area, which depends on the extent of the inter-rill erosion as well as the differentiation of SOC under the event (Kuhn *et al.*, 2009). Inter-rill sediments tend to accumulate in depositional crusts where organic C is broken out of regular structure and exposed to the atmosphere (Le Bissonnais *et al.*, 2005). It is far from trivial to scale up the end results of these processes on the SOC balance. In an attempt to detect respirational difference by field measurements, field C fluxes at different erosional phases over the course of a year were measured in Ohio, USA (Bajracharya *et al.*, 2000). However, difference was too subtle and masked by seasonal fluctuations of the climate. The effects of rainfall and shearing forces of run-off that were suggested to promote disaggregation of soil particles and increase respiration rates could therefore not be confirmed by the measurements in this field (Bajracharya *et al.*, 2000).

In summary, no uniform scientific foundation was found in the literature that erosion induces CO_2 emission. The studies illustrate the difficulties of scaling up and generalizing from measured results. The complexity of the erosion processes indicates the inaccuracy of using soil erosion loss estimates from agricultural fields to make a national CO_2 emission estimate. We conclude that there is a lack of solid scientific evidence for applying the previously-used method to estimate C emissions based on erosional events.

2.2.2. ALTERNATIVE METHODOLOGIES

Given the justification provided above the erosion-based method in the inventory needed a replacement. Four plausible methods are described that are in accordance with the IPCC methodology and increase in Tier level and, thus, complexity, work load, and data requirements. The four methods are: partial Tier 1 (tillage only), complete Tier 1, Tier 2, and Tier 3. The Tier 1 and 2 methods are based on the same calculations.

2.2.2.1. IPCC Tier 1 and 2 methodology

The IPCC methodology for Tier 1 (default) and Tier 2 approaches are based on Equation 3.3.4 of the 2003 guidelines (IPCC, 2003b) and Equation 2.25 of the 2006 guidelines (IPCC, 2006a). There are two main assumptions implied for calculating SOC change. First, the change in soil organic carbon (SOC) over the inventory period is equal to the difference in the SOC stocks at the end (SOC_0) and beginning ($SOC_{0\text{-}T}$) of the inventory period divided by D:

$$\Delta SOC = (SOC_0 - SOC_{0\text{-}T})/D,$$

where D is the time dependency of the stock change factors, which by default is 20 years. Second, SOC at any time can be calculated as the product of the soil C reference stock (SOC_{REF}), the stock change factors (F) and the area under the given management practice (A):

$$SOC = SOC_{REF} \times F \times A.$$

The C reference stock is the soil C stock under the reference condition, which in the default method is the native uncultivated soil. The reference stock is specific to climate zone (boreal, temperate moist, temperate dry, etc.) and soil type (high-activity clay, low-activity clay, spodic, sandy, wetland, or volcanic soils). The majority of Norwegian cropland can be considered as cold temperate moist climate (Borgen *et al.*, 2012a). According to the IPCC climate regions cold temperate moist climate is defined by a mean annual temperature between 0 and 10 °C and MAP/PET > 1 where MAP is the mean annual precipitation and PET is the potential evapotranspiration (IPCC, 2003b).

The default stock change factors are also determined by IPCC climate region. For each potential climate region, the soil type distribution needs to be determined. Stock change factors are given according to management practices of tillage intensity, residue input level, and land-use change (compared to the reference condition). Thus, there are values for three types stock change factors based on land-use, tillage and input level (F_{LU}, F_{MG}, and F_I). For land-use there are values for long-term cultivated, paddy rice, perennial/tree crop, and set aside < 20 yrs. For tillage there are values for full, reduced, and no-till types of tillage. For input levels there are values for low, medium, high without manure, and high with manure. The factors were estimated using global data and mixed linear statistical models with random and fixed effects as described in Ogle *et al.* (2005). Generally, the estimated stock change factors for the temperate climate have lower uncertainty (between 4% and 14%) than those estimated for the tropical climate (50%).

The main difference between the Tier 1 and 2 methods is that in Tier 1 the default values for stock change factors and soil C reference stocks are used whereas in the Tier 2 country-specific values are used (see Box 1). These can be based either on measured or modeled stocks and stock changes.

2.2.2.2. Partial Tier 1 (tillage only)

In the partial Tier 1, only the stock change factors for reduced and full tillage were assigned for all cropland soils and thus no changes were assumed to occur in residue inputs, crop rotations or manure inputs during the inventory period. According to the IPCC guidelines, the definition of reduced tillage includes only cultivation by harrowing with a shallow tine and not full-inversion plowing (IPCC, 2003b).

Default SOC reference stocks are based on the 2003 guidelines (IPCC, 2003b) and these are the same in the 2006 guidelines (IPCC, 2006a). The soil C reference stock for all Norwegian cropland was assigned the default value of 95 Mg C ha^{-1} as per cold, moist temperate climate for high-activity clay soils. To determine the soil C reference stocks data from the European Soil Database could be used, which places all Norwegian cropland soils as soils with high-activity clays (Borgen *et al.*, 2012a). Statistics Norway has available data (used in previous NIRs) on soil tillage. The default stock change factors are 1 for full tillage and 1.08 for reduced tillage (IPCC, 2006b).

Using activity data from the 2011 NIR submission, the calculations for the partial Tier 1 are illustrated in Box 2 for the inventory period 1990-2009. The uncertainties are 12% for the land-use factor, 5% for the reduced-tillage factor, and 95% for the soil C reference stock. For full tillage the stock change factor is 1 and an uncertainty error range cannot be given (as it is the reference condition). The uncertainty errors can be multiplied according to IPCC guidelines on the quantification of uncertainty (IPCC, 2003d). More details on uncertainty estimation are given in chapter 5 of this report.

Box 2: Partial Tier 1 calculation example

Soil organic carbon stocks at the beginning (1990) and at the end (2009) of the inventory period are:

SOC_{2009}: 95 Mg C ha^{-1} × 1 × 0 ha + 95 MgC ha^{-1} × 1.09 × 98112 ha = 10159.5 Mg C

SOC_{1990}: 95 Mg C ha^{-1} × 1 × 98112 ha + 95 MgC ha^{-1} × 1.08 × 0 ha = 9320.6 Mg C

The annual sequestration rate during the inventory period is:

ΔSOC = (101560 – 9321) Mg C / 20 yr = 41.9 Gg SOC yr^{-1} = 154 Gg CO_2 yr^{-1}

2.2.2.3. Complete Tier 1 method

A complete Tier 1 method would consider management effects on SOC related to tillage, crop rotation and inputs of plant residues and animal manure. The influences of these factors on soil C dynamics in agricultural systems are documented well (Paustian *et al.*, 2000) and should be accounted for in the inventory if possible. Furthermore, addition of animal manure can have a large impact on SOC storage because of the larger humification efficiency (i.e. ability of the added C to form stable compounds with soil humus) of manure than plant residues. It is therefore likely that areas that have undergone drastic changes in manure application rates would have associated changes in SOC stocks. This would be accounted for in a complete Tier 1.

To assign the stock change factors for tillage and input level, knowledge of the most common crop rotations is necessary. Agricultural statistics of individual crops can, based on simple assumptions, serve to estimate the areas of specific crop rotations. Specifically, the areas of grass-leys and cereals within defined agrozones can be used to estimate the crop rotations based on the individual crop type proportions within each agrozone (Borgen *et al.*, 2012a). Statistics of livestock numbers or manure availability are needed to estimate the ratio of each crop rotation with and without manure application. It should be noted that the assumptions used to distribute the areas under each crop rotation are difficult to check and also there is a limit to how many rotations can be considered. An example of a complete Tier 1 approach for Norwegian cropland was given in Borgen *et al.* (2012a).

2.2.2.4. Tier 2 method based on modeling

A Tier 2 method would consider the effects of crop rotations, manure application, straw residue incorporation and tillage frequency on SOC changes in a country-specific manner. This method is essentially the same as the complete Tier 1 except that both SOC reference stocks and stock change factors are estimated specially for Norway. The areas of each crop rotation are identical to the Tier 1.

If limited empirical data are available to estimate country-specific stock change factors and SOC reference stocks (which is the case for Norway), a well-tested and validated model can be used for this purpose. Model simulations using the Introductory Carbon Balance Model, ICBM (Andrén and Kätterer, 1997) was used to generate stock change factor and references stocks specific to soil type, crop rotation and climatic region. Stock change factors were estimated for eight crop rotations, with and without animal manure application for 31 agrozones in Norway (Borgen *et al.*, 2012a). The soil C reference stocks were calculated as the steady state of the model for a defined reference condition. Data of climatic variables and crop yields are necessary to run ICBM. Temperature, precipitation and potential evapotranspiration in a time series of 1980-2009 based on 32 000 measurement points on Norwegian cropland were compiled and mean daily values for 31 agrozones were calculated (Borgen *et al.*, 2012a). In the Tier 2, the reference condition and the time-dependency of the stock change factors (D) can be defined specifically to the conditions of the country. In the above-mentioned study, the reference condition was assumed to be perennial grass cultivation and the time-dependency was increased to 30 year. This was appropriate for Norway because the cool wet climate slows decomposition rates and prolongs the time between steady state conditions when management practices are changed.

2.2.2.5. Tier 3 method based on ICBM simulations

A Tier 3 method implies using an ecosystem model that considers the combined effects of soil, climate and agricultural management on soil C changes dynamically. The Swedish national inventory uses the ICBM to simulate the C balance on a regional level (Andrén *et al.*, 2004). The model is developed under Swedish conditions and has been tested internationally for several regions including Canada, Sub-Saharan Africa, North and South America, and the Nordic countries (Bolinder *et al.*, 2008; Salazar *et al.*, 2011; Juston *et al.*, 2010; Lokupitiya *et al.*, 2012; Kätterer and Andrén, 1999). It is a good choice for Norway given the relative climatic similarities with Sweden and the lack of long-term data to develop a Norwegian model.

Using the ICBM dynamically to estimate annual changes in soil C stocks of Norwegian cropland, requires annual data of all crops, climate (precipitation, temperature, and potential evapotranspiration) for the whole inventory period, and soil types stratified at an appropriate scale. Gathering of annual yield data for specific strata can be a disadvantage of the Tier 3 method. A preliminary test of dynamic ICBM simulation of C stock changes in Norwegian cropland resulted in rather large annual fluctuation in estimated emissions (Borgen *et al.* in press). Explaining annual variation can be cumbersome for inventory compilers also in relation to key category identification (see Box 3 for explanation). The advantages of using a dynamic model to simulate annual soil C changes include that long-term overestimation of C stock changes appears to be avoided, compliance with reviewers' and IPCC commendation. However, developing and implementing a Tier 3 method in the GHG inventory should ideally be accompanied by model validation where the ability of the model to accurately predict measured SOC changes is evaluated, as well as proper uncertainty estimates. Although the proposed model (ICBM) was developed and tested under Swedish conditions, it is recommended to test the model against the SOC measurements from the few long-term experimental sites that are available in Norway.

2.2.3. EMISSIONS FROM MINERAL SOILS REPORTED IN THE INVENTORY

For the 2013 NIR submission the Tier 2 method was used. Statistics Norway provided the necessary data of crop type areas and manure availability. From the method application a few observation can be made. Norwegian cropland appears to be a small net sink of C (Figure 3). The activity data indicated that since 1990, the number of cattle decreased substantially while chicken and hens increased, which has caused a change in the type of manure applied. The manure production therefore decreased. However, the area of cropland remaining cropland declined also and the net result was an apparent increase in the area that receives manure applications. Increasing C input to agricultural soils is the main cause of net C sequestration (Paustian *et al.*, 2000). The annual C sequestration rates were relatively small and less than 14 Gg C yr^{-1}.

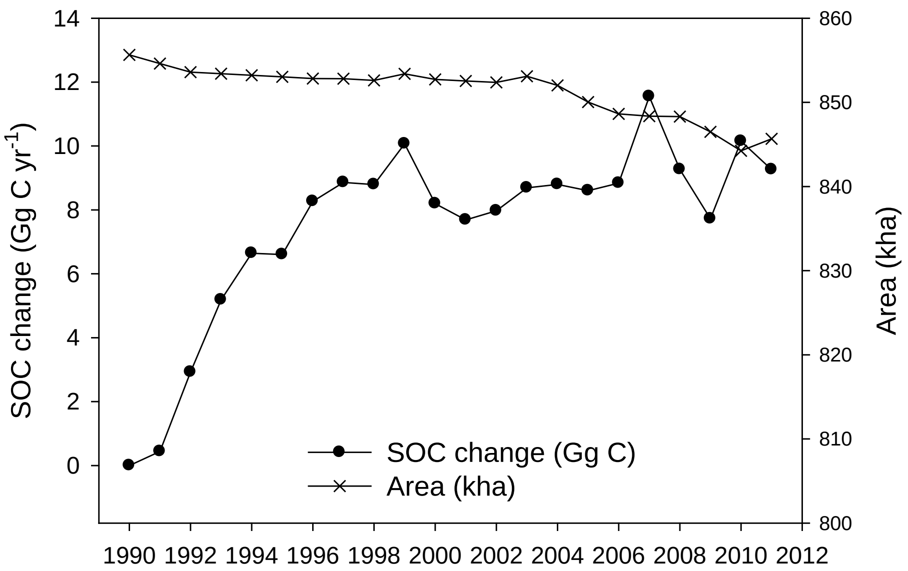

Figure 3: Annual changes in soil organic carbon (SOC; Gg C yr^{-1}) in mineral soils and the area (kha) of cropland remaining cropland from 1990 to 2011. Values presented are identical with those reported in the National Inventory Report 2013 submission.

As mentioned above, this method is associated with assumptions regarding crop rotations and uncertainties are probably large. The implied assumptions of the Tier 1 and 2 methodologies are also accompanied by error, because soil C accumulation may not occur in a linear manner with respect to C input (Stewart *et al.*, 2007). The linear assumption of the IPCC lower tiered methods (1 and 2) have been criticized by Sanderman and Baldock (2010), who strongly advocated the use of dynamic SOC modeling for a more accurate accounting. Sanderman and Baldock (2010) showed theoretically how positive management changes are likely to be overestimated by the lower Tier methods due to the steady state assumptions. A preliminary study confirmed this by comparing the three IPCC tier methods for estimation of SOC changes in Norwegian cropland (Borgen *et al*., in press). In this study total net C uptake over the whole inventory period 1990-2011 was 7 times lower using the tier 3 method instead of Tier 1 or Tier 2 methods. Based on these findings, it can be concluded that the switch to a Tier 3 method has a more drastic effect on the estimated emissions than a change between the two lower Tier methods.

2.3. Organic Soils

Organic soils make the largest contribution of CO_2 emissions within the source categories for cropland. It is a key category with a large uncertainty attached to its estimation. See Box 3 for explanation of key categories in the UNFCCC national inventory reporting. Cultivated organic soils are defined as soils with a topsoil layer (0-30 cm) with more than 10% C. The area of cultivated histosols has gone from approximately 9% of the cropland area to 8% over the inventory period (1990-2011).

Box 3: Key category

The 2003 IPCC guidelines' chapter on cross-cutting issues defines the term key category. A key category is a sink/source category with an emission estimate that has a significant influence on the whole inventory of a country either in terms of the absolute level or the trend. The definition of key categories includes estimates of the emissions and the uncertainty.

2.3.1. METHODOLOGY

A Tier 2 method was used for estimation of CO_2 emissions from organic soils on cropland in the 2013 NIR. The Tier 2 method implies that C loss (C_{Loss}) is estimated as the product of a country-specific emission factor (EF) and the area (A) of organic cultivated soil according to Equation 2.26 (IPCC, 2006a):

$$C_{LOSS} = \Sigma (A \times EF),$$

where the summation is applicable if stratified emission factors are available, e.g. by climate or crop type. Norway uses two emission factors depending on the C concentration of the topsoil. Highly organic soils with more than 20% C were assumed to have an emission factor of 10 Mg C ha^{-1} yr^{-1} and for mixed organic soils with 10-20% C, an emission factor of 5 Mg C ha^{-1} yr^{-1} was used. As no regional or crop-specific stratification is applied, the ratio of highly organic and mixed-organic soil (1:2) for all cultivated histosols in Norway was used, which gave a mean national emission factor of 6.67 Mg C ha^{-1} yr^{-1}. The emission factors were derived by expert judgment by an experienced researcher at Bioforsk (Grønlund, 2012, *pers. comm.*).

2.3.1.1. Data

The area of cultivated organic soils was estimated using land classification maps from the Norwegian Forest and Landscape Institute (DMK and AR5[1]) and a soil sample database from Bioforsk (Grønlund *et al.*, 2008b). At the time of the analysis, approximately 50% of the cultivated area in Norway had been mapped and the total area of cultivated organic soils was estimated between 75 and 90 kha, with a final corrected value of 83 170 ha. This value was considered realistic in 1994 and used to extrapolate a time series for the inventory period. From 1994 subsidies were no longer provided for cultivation of new organic soils and after

[1] DMK: Digital field map; AR5: land-use resource map in 1:5000 scale. Both maps produced by NFLI: http://www.skogoglandskap.no/temaer/markslag

then a smaller increase in the area of cultivated histosols of 200 ha yr^{-1} was assumed. Also, it can be assumed that 1.4% yr^{-1} of the area transits into mineral soil or is taken out of production. This time series entails substantial assumptions; however, it is the best available at the present time.

2.3.2. EVALUATION OF EMISSION FACTORS

In the 2013 NIR, emissions from organic soil were found to be a key category because of size of emission and uncertainty level (CPA, 2013). Given the importance of this source category, the Norwegian emission factor was compared with those used in the NIRs of other Nordic countries. The 2011 GHG inventory for Sweden used differentiated emission factors according to cultivation intensity. The emission factors of the Swedish NIR specific to crop type/rotation were: 0.50 (pasture), 3.15 (leys), 4.7 (cereal), and 7.9 (row crops) Mg C ha^{-1} yr^{-1} (Swedish-EPA, 2011b). The rates are derived from measured subsidence rates on eight Swedish sites described in two reports from The Swedish University of Agricultural sciences (Berglund, 1989; Berglund *et al.*, 2009). The 2011 Danish NIR referred to an article in preparation where emission factors for highly organic soils (> 12%C) were reported for annual crops/grass in rotation as 8.7 Mg C ha^{-1} yr^{-1} (NERI, 2011). They also list an emission factor for mixed organic soil (6-12%C), which is approximately half the value (4.36 Mg C ha^{-1} yr^{-1}). For the 2011 Finnish NIR, they used two emission factors, one for grass (4.1 Mg C ha^{-1} yr^{-1}) and one for other crops (5.7 Mg C ha^{-1} yr^{-1}) according to Maljanen *et al.* (2007). Finally, the IPCC default emission factor for cold temperature climate is 5 Mg C ha^{-1} yr^{-1} (IPCC, 2006b). Compared to the default values and the emission factors in use by other Nordic countries, it can be concluded that the Norwegian national mean of 6.67 Mg C ha^{-1} yr^{-1} seems plausible.

Searching for empirical data on CO_2 emissions from agricultural land in Norway, we found measurements from four fields (two with perennial grass, one with annual ryegrass, and one abandoned perennial grass) located in the northern part of the country, near Bodø (Grønlund *et al.*, 2008a; Grønlund *et al.*, 2006; Klove *et al.*, 2010). This is also the only Norwegian site included in the extensive literature review by Maljanen *et al.* (2010), which summarizes results from over 100 studies of measured GHG emissions in the Nordic countries. These studies show no indication that more intense cultivation would lead to higher emissions, in fact the opposite was the case. Grønlund *et al.* (2006) measured net ecosystem C losses of 7.4 Mg C ha^{-1} yr^{-1} for the perennial grass, 4.4 Mg C ha^{-1} yr^{-1} for annual ryegrass, and a mean on all four sites of 6.0 Mg C ha^{-1} yr^{-1}. The same was the case for a Danish study, where measurements of ecosystem respiration over one year including three location and tree cropping systems (annual cropping, grain-ley rotation and permanent grass) were on two of the sites smallest (1.5 and 1.6 Mg C ha^{-1} yr^{-1}) for the annual rotations (Petersen *et al.*, 2012). Thus it seems difficult to make conclusions based on the Norwegian measurements (and the Danish study) about the effect of crop rotation on C emissions from organic soils. Furthermore, the Norwegian studies oppose the trend in the IPCC default emission factors for cropland and grassland as the permanent grasslands had higher emissions than the annual grass rotation (IPCC, 2006b, c).

In conclusion, measurements are highly variable and a consistent relation between cropping systems and emission levels does not seem to emerge from the available Norwegian studies. Other factors such as the groundwater table level and the local climate could influence C emissions more than the type of cropping system (Armentano and Menges, 1986; Maljanen *et al.*, 2010; Petersen *et al.*, 2012).

2.3.2.1. Improvements

Estimation of the area of cultivated organic soil for the base year, i.e. 1994 when cultivation of organic soil was at its highest, has a large influence on the emission estimate. Improving the area estimate could be done by updating the work of Grønlund *et al.* (2008b) to include the areas mapped since 2008. Additionally, the soil data bases of NFLI provide more detailed soil classification than the database used previously and data is continuously being collected with the objective to map all agricultural land in Norway. At the moment approximately 50% of the agricultural area has been mapped. Combing these databases would provide a good foundation for making a stratified analysis to determine the potential areas of organic soils under grassland (which are currently assumed to be negligible). Also, it could allow potential crop- or climate-specific emission factors if deemed necessary in the future. Another aspect is to investigate the assumptions implied regarding the trend over time in cultivation of organic soils.

To improve the estimation of the emission factors and include uncertainty ranges, additional resources are required. Globally, much activity is currently going on, however, field measurements are time consuming and require many seasons and locations to deduce reliable emission factors specific to the environmental and climatic conditions. Determining the most important factors that influence the decomposition processes in cultivated organic soil is necessary.

2.3.3. EMISSIONS FROM ORGANIC SOILS

The area of cultivated organic soils is assumed to decline (due to peat layer subsidence) over the years and emissions are therefore decreasing during the inventory period (Table 5). Emissions for 2011 are substantial and equal to 1 750 Gg CO_2 yr^{-1}. This source of emissions is a key category in the Norwegian national inventory.

Table 5: Areas, soil organic carbon (SOC) changes and CO_2 emissions estimated from cultivated organic soils.

Year	Area (ha)	SOC change (Gg C yr^{-1})	CO_2 emission (Gg CO_2 yr^{-1})
1990	84657	-564	2069
1991	84736	-565	2071
1992	84813	-565	2073
1993	84051	-560	2055
1994	83297	-555	2036
1995	82551	-550	2018
1996	81812	-545	2000
1997	81080	-541	1982
1998	80356	-536	1964
1999	79639	-531	1947
2000	78929	-526	1929
2001	78227	-522	1912
2002	77532	-517	1895
2003	76843	-512	1878
2004	76162	-508	1862
2005	75488	-503	1845
2006	74820	-499	1829
2007	74160	-494	1813
2008	73506	-490	1797
2009	72859	-486	1781
2010	72219	-481	1765
2011	71585	-477	1750

3. GRASSLANDS

In the Norwegian GHG inventory, grasslands are defined as areas covered with grass that may be mechanically harvested or grazed but never plowed and that may be cultivated intensively by fertilization, harvested mechanically and improved by selected species (CPA, 2013). The definition is based on the NFI, SSB and IPCC. In the Norwegian NFI, grazing lands (*kulturbeite*) are assigned to lands where annual grazing occurs and at least 50% of the area is covered by grass species. Trees, stumps, and rocks may be present but grazing is considered the most important land use form either as surface-cultivated grass leys or unimproved grazing land (NFLI, 2011). Statistics Norway (SSB) further defines the two types of grassland management as follows. Surface-cultivated pastures (*overflatedyrka eng*) are areas with shallow topsoil layers, often with surface rocks, that can be mechanically harvested but are not plowed. Unimproved grazing land (*innmarksbeite*) are lands that never mechanically harvested (or plowed) but only grazed and can be considered semi-natural landscapes. Furthermore, *innmarksbeite* is defined by a minimum of 50% of the area being covered by grasses or grazable herbs and enclosed by a fence or a natural barrier. It is also required to be grazed or harvested at least once a year to be eligible for subsidy support. Finally, according to the IPCC grasslands includes rangelands and pastures lands that are not considered cropland (IPCC, 2006c).

Compared to earlier inventory reports, a new Tier 1 method for mineral soils was implemented in the 2013 NIR submission for grassland remaining grassland. The emissions caused by C stock changes in living biomass are also new because they are based on the tree biomass estimated from the revised NFI database. However, the methodology for living biomass is basically the same as previous years.

3.1. Living biomass

3.1.1. METHODOLOGY

Emissions from changes in living biomass in trees on grasslands are reported using the stock-difference method (Tier 3) based on the NFI measurements and models. The stem diameter and tree height measurements made on NFI plots are used as input for single tree allometric regression models developed in Sweden (Marklund, 1988; Petersson and Ståhl, 2006). Substantial amounts of woody biomass can be recorded on grasslands because the NFI classifies grassland over forest land if grazing is the more dominant land-use. This means that lands may reach the forest definition for tree cover but still be classified as grassland if grazing seems to be the more important land-use. More details can be found in NIR 2013 (CPA, 2013). The changes in herbaceous C stocks are not accounted for in the inventory and that constitutes a potential improvement.

3.1.1.1. Improvement: estimation of herbaceous C stocks

The default Tier 1 methodology states that herbaceous above- and below-ground biomass is generally negligible and accounting is not needed (IPCC, 2003). However, below-ground biomass in grasslands can be large due to the elaborate root systems. Tier 2 or 3 approaches consider the below-ground biomass in the herbaceous component. Due to the time consumption and complications of measuring below-ground biomass, simpler methods are often used involving multiplication of root/shoot ratios (also called expansion factors) with above-ground biomass. For Norway, an estimate of C stock changes in below-ground biomass could be made by using the default IPCC expansion factor of 4 for the cold, temperate moist climate (IPCC, 2003), and a rough national estimate of above-ground biomass. The uncertainty associated with the default expansion factor is rather large (±150%). A country-representative value may be estimated instead based on the allometric equations developed for several crops under Nordic and temperate conditions (Bolinder *et al.*, 2007; Bolinder *et al.*, 2010). Although, it may be possible to estimate root/shoot ratios, it is not likely to be prioritized because the C stocks are relatively small compared to those estimated for living biomass in trees.

3.1.2. EMISSIONS/REMOVALS FROM CHANGES IN LIVING BIOMASS

The Tier 3 stock-difference method was used to provide emission estimates for living biomass in trees. During the inventory period 1990-2011, C stock changes caused large CO_2 emissions in some years (e.g. 2000, 2005, and 2006) and removals in other years (Table 6). This is mainly due to fluctuations in tree harvesting.

Table 6: Estimated C (carbon) gains and losses in living biomass of tress on grassland from 1990 to 2011. Losses are shown with a negative sign and negative emissions indicate CO_2 removals from the atmosphere.

Year	C gains (Gg C yr^{-1})	C losses (Gg C yr^{-1})	Net C change (Gg C yr^{-1})	Emissions (Gg CO_2 yr^{-1})
1990	11.0	-0.6	10.4	-38.0
1991	11.7	-0.7	11.0	-40.3
1992	11.7	-0.7	11.0	-40.3
1993	12.7	-0.7	12.0	-44.0
1994	12.1	-0.7	11.4	-41.9
1995	13.7	-0.8	12.9	-47.3
1996	13.5	-0.8	12.7	-46.6
1997	13.3	-0.8	12.6	-46.0
1998	13.8	-0.8	13.0	-47.8
1999	0.2	0.0	0.2	-0.8
2000	0.9	-22.3	-21.4	78.5
2001	0.0	-3.9	-3.9	14.2
2002	2.0	0.0	2.0	-7.2
2003	0.2	0.0	0.2	-0.6
2004	0.8	0.0	0.8	-2.8
2005	0.5	-13.2	-12.7	46.7
2006	3.3	-16.6	-13.3	48.6
2007	0.6	-1.5	-0.9	3.3
2008	0.0	-0.2	-0.2	0.6
2009	0.0	-0.7	-0.7	2.6
2010	14.1	0.0	14.1	-51.6
2011	20.5	0.0	20.5	-75.1

3.2. Mineral Soils

In previous NIRs, it was assumed that C stocks in grassland soils are in steady state, and that management changes do not cause net CO_2 emissions or removals (with the exception of those influencing erosion). Grasslands (as defined in the inventory) are not plowed, but they may be subject to mechanical harvesting, fertilization and/or grazing, which can influence the soil C balance.

3.2.1. METHODOLOGY

Previously, the modified Tier 2 method, which was based on erosion, was used to estimate emissions from mineral soils on grassland. As discussed under the cropland chapter, this method was abandoned in the 2013 NIR and a Tier 1 approach was used instead. The default methodology was described in more detail under cropland (section 2.2.2). Briefly, the method is based on stock change factors and soil C reference stocks. The annual changes in soil organic carbon (SOC) can be calculated by:

$$\Delta SOC = (SOC_0 - SOC_{0\text{-}T}) / D,$$

where D is the time dependency of the stock change factors, which by default is 20 years; Equation 2.25 (IPCC, 2006a). The beginning and end of the inventory period are 0-T and 0, respectively. If T is larger than D, T should replace D in the equation with T being the time of the inventory period.

The SOC stock for any year of the inventory period can be calculated as the product of the soil C reference stock (SOC_{REF}), the stock change factors (F) and the area under the given management practice (A):

$$SOC = SOC_{REF} \times F \times A.$$

The C reference stock is the soil C stock under the reference condition, which in the default method is the native uncultivated soil. The reference stock is specific to climate zone (boreal, temperature moist, temperature dry, etc.) and soil type (high-activity clay, low-activity clay, spodic, sandy, wetland, or volcanic soils). Exposed bedrock should be assigned a reference stock of zero.

3.2.1.1. Data

Area data of the two grassland management types were collected by the Norwegian Agricultural Authorities (NAA) and compiled by Statistics Norway. The data were collected in form of a questionnaire used by farmers to apply for subsidies. National statistics from Statistics Norway reveal a general trend in grassland management. The area of unmanaged grazing land has been increasing while the area of improved grassland has decreased (Table 7). The data were stratified into eight regions (Figure 4), and this was also done for the soil data.

The regions were identified based on a combination of municipalities and selected climatic variables, i.e. temperature, precipitation and potential evapotranspiration. Norwegian municipalities (429) were divided into 19 counties. The NAA operates with seven production zones when allocating subsidies. To obtain the eight zones, we stratified the production zones per county, which yielded 31 agrozones (identical to those for cropland). For each agrozone, the climate variables mentioned above were collected from 32 000 measurement stations on agricultural land and averaged into annual means based on a 30-year data series (1980-2009) as described in Borgen *et al.* (2012a). Based on the annual means, the 31 agrozones were grouped as close as possible to the production zones, which yielded the eight regions shown in Figure 4.

Table 7: Areas of unmanaged, improved and total grasslands from Statistics Norway and the areas of grassland remaining grasslands for 1990-2011 identified by the National Forest Inventory (NFI).

	Statistics Norway areas (ha)			**NFI areas (ha)**
Year	Unmanaged grassland	Improved grassland	Total grassland	Grassland remaining grassland
1990	81 357	27 180	108 537	220 883
1991	85 453	26 973	112 426	220 182
1992	89 735	27 153	116 888	219 481
1993	94 215	25 975	120 190	218 780
1994	98 422	26 050	124 471	218 079
1995	100 719	26 447	127 166	217 378
1996	103 008	26 672	129 681	216 677
1997	107 900	25 478	133 378	215 976
1998	111 474	29 179	140 653	215 276
1999	121 607	29 517	151 123	213 473
2000	129 133	28 997	158 129	213 473
2001	132 293	28 244	160 536	212 392
2002	135 408	28 067	163 474	209 688
2003	137 061	27 382	164 443	208 246
2004	139 083	26 951	166 033	208 246
2005	142 407	26 770	169 177	206 894
2006	145 588	26 110	171 698	206 894
2007	149 207	25 375	174 582	205 993
2008	150 810	24 327	175 137	204 731
2009	152 352	22 455	174 806	201 126
2010	155 136	20 704	175 839	198 422
2011	156 452	20 119	176 571	196 770

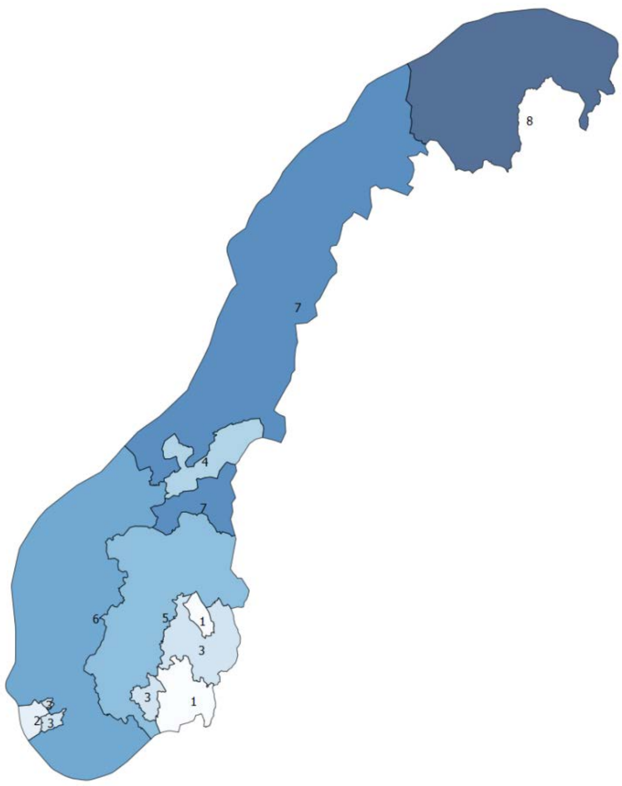

Figure 4: Stratification into eight regions (labeled 1-8) based on county, productivity level, and climate.

3.2.1.2. Assigning the stock change factors and soil C reference stocks

Default stock change factors were used (IPCC, 2006d). The land-use factor for all grassland is one (F_{LU} = 1). For grasslands there are four management factors (F_{MG}): 1) unimproved/nominal (non-degraded) grassland, 2) moderately degraded grassland, 3) severely degraded grassland, and 4) improved grasslands, In addition, there are two input factors (F_I) for nominal and high input levels. For the Norwegian Tier 1 application, the management factors were assigned as F_{MG} = 1 as per nominally managed (non-degraded) grassland for unmanaged grazing land and F_{MG} = 1.14 as per improved grassland for surface-cultivated grassland. The latter factor is assigned to grassland that is sustainably managed with moderate grazing pressure and that received one improvement of fertilization, species improvement, or irrigation. The input factor is only applied to improved grassland and is set to one for all due to lack of activity data. Under Norwegian conditions, it is fair to assume that most grassland receives only one improvement in form of fertilizers, because the common practice is that grazing areas are seldom reseeded (except in the case of severe frost damage) and irrigation is not practiced due to sufficient rainfall.

The soil C references stocks were assigned for the cold temperate moist climate and the distribution of the IPCC soil types were then determined within each of the eight regions. This was done by analyzing the NFLI soil database with a soil classification system based on the World Reference Base (WRB) for soil resources. At the present time, soil mapped areas cover approximately 50% of all agricultural land in Norway. The percentage of the grassland area currently sampled varies greatly from 1% in region 8 to 34% in region 4; however, this is the best data available. High-activity clay soils predominate in all regions, expect in region 2 where spodic soils make up almost one third (Figure 5).

The soil C reference stocks (SOC_{REF}) for the cold temperate moist climate zone in 0-30 cm depth are 95 Mg C ha^{-1} for HAC, 71 Mg C ha^{-1} for sandy soils, 115 Mg C ha^{-1} for spodic soils, and 87 Mg C ha^{-1} for wetland soils (IPCC, 2006a). Soil C stock changes were first calculated per region for all soil types where after these were multiplied by the fractions under each soil type to get the final stock changes.

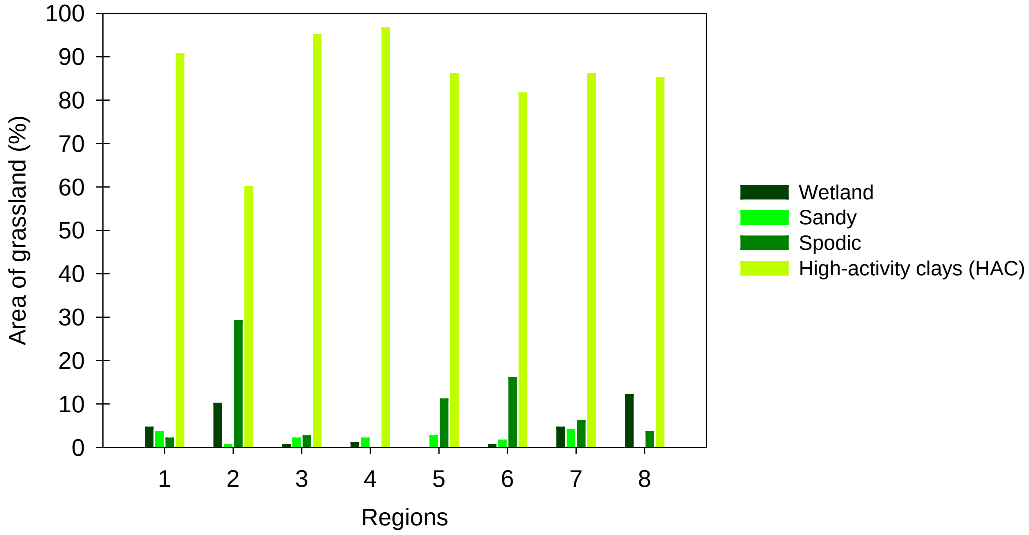

Figure 5: Distribution of grassland areas on the IPCC soil classification per region. HAC: high-activity clay soils include leptosols, fluvisols, phaeosem, albeluvisols, luvisols, umbrisols, cambisols, and regosols. Wetland soils: gleysols. Sandy soils: arenosols. Spodic soils: podzols.

3.2.1.3. Alternative methods and improvements

Emission estimates made with the Tier 1 method are associated with large uncertainty (± 90%). It is possible to use a Tier 2 method either based on measurements and/or modeling. SOC content on grasslands have been measured at several locations in Norway. In a 9 x 9 km grid, areas of 0.95 km^2 have been soil mapped on agricultural land throughout the country. These data can be used to estimate the SOC status regionally and provide estimates of soil C stocks for the two grassland management types. However, measurements are not available over time and it may be useful to use a model to simulate the SOC changes and thereby generate country-specific stock change factors. This could for example be the ICBM (Andrén and Kätterer, 1997) or the Swiss Oensingen Grassland Model (De Bruijn *et al.*, 2012). Modeling stock change factors does require additional data (e.g. C inputs and climatic variables). A more immediate utilization of the soil data would be to compare the measured stocks with the global default soil C reference stocks, which would enable an accuracy evaluation of the Tier 1 method for the Norwegian conditions.

3.2.2. EMISSIONS FROM MINERAL SOILS ON GRASSLAND

Using the Tier 1 method, a net C loss is estimated for Norwegian grassland (Table 8). The emissions can be explained by the activity data that show a tendency towards more extensive management practices of grassland and thus smaller C inputs. The area of improved grassland (managed as surface-cultivated with mechanical harvesting) has been reduced while the area of unmanaged grazing land has been increasing. It should be pointed out that the activity data available (shown in Table 7) have not been overlaid spatially. Therefore, it has not been confirmed that the changes in grassland management actually did occur on NFI plots of grassland remaining grassland. Further analyzes of the available data is necessary to provide information of the actual trend in grassland management practice in Norway.

Table 8: Changes in soil organic carbon (SOC) and CO_2 emissions from 2000 to 2011 from mineral soils on grassland caused by management changes as estimated by Tier 1.

Year	SOC changes ($Gg\ C\ yr^{-1}$)	CO_2 emissions ($Gg\ CO_2\ yr^{-1}$)
1990	0.0	0.0
1991	-1.3	4.8
1992	-2.4	8.7
1993	-4.4	16.2
1994	-5.5	20.1
1995	-5.8	21.1
1996	-6.1	22.5
1997	-8.2	30.0
1998	-6.4	23.3
1999	-7.6	27.7
2000	-9.4	34.6
2001	-10.4	38.0
2002	-10.6	38.8
2003	-11.2	41.0
2004	-11.7	42.8
2005	-12.2	44.6
2006	-12.8	47.0
2007	-13.6	49.9
2008	-14.3	52.5
2009	-15.3	56.2
2010	-16.4	60.2
2011	-15.9	58.5

The largest annual emission (in 2010) corresponds to a C loss rate 82.7 kg C ha^{-1}, which is reasonable considering the range of values reported by Ogle *et al*. (2004).

3.3. Organic soils

In the 2013 NIR, emissions from all cultivated organic soils were reported under cropland. Previously, 90% of the area was reported under grassland because 90% of the organic soil samples analyzed by Bioforsk were taken on grass vegetation (NIJOS, 2005). The soils were analyzed for farmers to give fertility assessment and were therefore primarily taken on soils with cultivation potential and thus not likely to be unimproved grazing lands. Surface-cultivated pastures may be fertilized and these could potentially be on organic soils. But without further data analysis it seems a reasonable first approximation to consider cultivated organic soils as cropland only.

3.3.1. EVALUATION OF THE OLD METHODOLOGY

In previous submission, the vast majority of the CO_2 emissions from grassland remaining grassland arose from organic soils (histosols). Defining grassland as permanent not-plowed grass fields, removes all the cultivated histosols with grass vegetation to cropland because such lands can be considered plowed and in a rotation. Assuming all grassland soils are mineral is a decent approximation until regionalized overlays of land-use and soil types have been analyzed.

3.3.2. POTENTIAL METHODOLOGY

The IPCC guidelines offers a default emission factor for organic soils on grasslands, which is one fourth (0.25 Mg C ha^{-1} yr^{-1}) of that for cropland (1 Mg C ha^{-1} yr^{-1}) (IPCC, 2006c; IPCC, 2006b). The assumption is based on a literature review by Armentano and Menges (1986), who conclude that the water table in annual cultivated fields, i.e. grains and vegetables, is usually lower than on permanent pastures (because pastures are drained to a lesser extent) and this warrants larger SOC decomposition rates on arable fields.

3.3.2.1. Data and suggested improvements

Currently, it is assumed that organic soils with grass are under regular cultivation, and what is classified as grassland (surface-cultivated pastures and unmanaged grazing land) is not on organic soils. This assumption may not be entirely true. In fact other data sources, such as the DMK statistics, show that peatland areas were also identified as grasslands. Data is available at NFLI to improve the accuracy of this assumption.

For example, overlaying land classification maps (DMK, AR5) and soil maps (Norwegian Soil Resource Data Base) the area estimation can be improved and also stratified regionally. An initial preview of these data hinted that there are areas identified as both grassland and organic soils, however the extent has not been quantified.

The UNFCCC inventory review reports have repeatedly encouraged Norway to improve the estimation of emissions from organic soils due to its key category definition (UNFCCC, 2013). Although it seems possible to improve the area estimation, the emission factor may, however, not be as easily improved. Even within the Nordic countries there is little consistency regarding which factor values to use. Sweden used a low emission factor for organic soils under pasture of 0.5 Mg C ha^{-1} yr^{-1} (Swedish-EPA, 2011a), whereas the Danish emission factors were higher for improved/fertilized permanent grasslands of 5.17 and 2.59 Mg C ha^{-1} yr^{-1} for highly organic and mixed-organic soil, respectively (NERI, 2011). Until more measurements are gathered, the best emission factor does not seem to emerge clearly.

4. LAND-USE CONVERSIONS

Areas of land that were converted to cropland or grassland since 1990 were estimated using the NFI database (CPA, 2013). The methods used for estimation of emissions on land converted to cropland and land converted to grassland were the same and this was the case for all three sink/source categories (living biomass, soils and dead organic matter). The methodologies and emission estimates are therefore described together for both land-use change categories. Land converted to cropland was primarily of forest origin although there were also a few plots of grassland and settlements (Figure 6A). Land converted to grassland was exclusively from forest land (Figure 6B), except for an area of 540 ha of wetland that was converted in 2011 (data not shown).

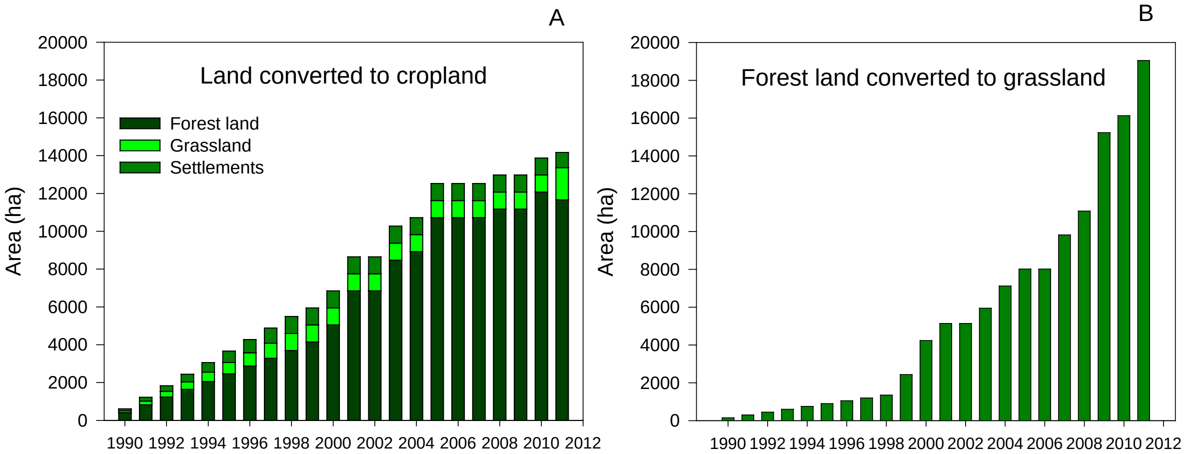

Figure 6: Accumulated land areas (ha) converted to cropland from forest land, grassland, and settlements (A) and accumulated forest land (ha) converted to grassland (B).

4.1. Living biomass

4.1.1. METHODOLOGY AND EMISSIONS

The method used for estimating emissions from living biomass on land in conversion is the Tier 3 method also used for grassland remaining grassland (section 3.1.1). The method combines NFI data with single-tree allometric biomass models. According to the NFI data, there were only C stock changes occurring on forest land converted to either cropland or grassland. Carbon stock change in living biomass varied over the years (Figure 7) causing net emission of CO_2 for most of the years.

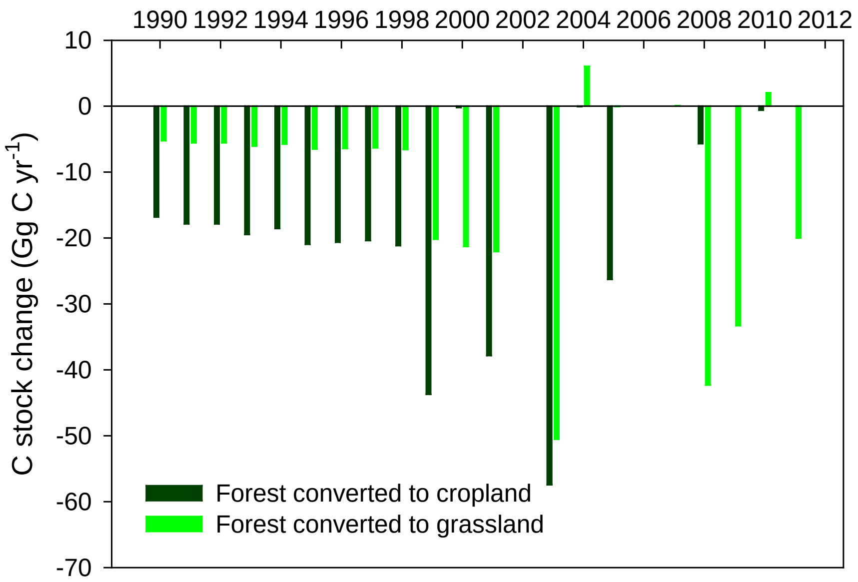

Figure 7: Carbon stock change in living biomass (Gg C yr^{-1}) from land converted to cropland or grassland from 1990 to 2011.

Although no actual tree measurements are recorded after an NFI plot is converted to cropland, it is likely to assume that all biomass is lost in the year of the conversion. On plots converted to grassland, tree records are continued and both biomass losses and gains are reported in the inventory.

4.2. Mineral soils

A new Tier 1 methodology for soil emissions on land converted to cropland or grassland was implemented for all land-use conversion in the 2013 NIR submission.

4.2.1. METHODOLOGY

In the default methodology, changes in SOC are estimated as:

$$\Delta SOC = (SOC_0 - SOC_{0\text{-}T})/D,$$

where D is the time-dependency of the stock change factors and is by default 20 years. SOC_0 is the stock of the land use that the land has been converted to and $SOC_{0\text{-}T}$ is the stock of the land use from where the land was converted. The stocks can be stratified regionally according to the IPCC-identified climate zones, however all Norwegian forests, cropland and grassland are considered in the cold temperate moist climate zone. National mean SOC stocks were based on the default IPCC reference stocks per land-use category (IPCC, 2006a).

4.2.1.1. National SOC stock estimates per land-use category

A mean national SOC stock was estimated for each land-use category based on the default soil C reference stocks (SOC_{REF}) considering the soil type distribution of the specific land-use category and for cropland and grassland management stock change factors as well.

Forest land: The distribution of IPCC soil types of Norwegian forests was based on national registrations (de Wit and Kvindesland, 1999; Grønlund and Solbakken, 1987) and assuming that brunisols (according to the Canadian classification system used at that time) with low pH were categorized as spodic in WRB. The result was 12% as wetland soils, 77% as spodic soils, and 11% as high-activity clay (HAC) soils. Stock change factors (land-use, management and input factors) under forest land are by default equal to one. The mean forest SOC stock estimate was therefore equal to:

$$SOC_{forest} = (0.12\times87 + 0.77\times115 + 0.11\times95)\ \text{Mg C ha}^{-1} = 109.4\ \text{Mg C ha}^{-1}.$$

Cropland: In addition to soil type, the mean cropland SOC stock also considers management practice. A mean stock change factor was derived as the product of the default tillage, management and land-use factors listed in the 2006 guidelines (IPCC, 2006b). The mean stock change factor was determined for each of the 16 crop rotations used in the Tier 2 for cropland remaining cropland and these were weighted by the national mean area under each crop rotation. Cropland was assumed to be only on soils with high-activity clays. Multiplying the default soil C reference stock of 95 Mg C ha^{-1} with the weighted national mean sock change factor produced a SOC stock estimate for cropland of 76.9 Mg C ha^{-1}.

Grassland: The SOC stock for grassland was based on the area fraction of the two grassland-management practices and the national distribution of IPCC defined soil types for the grassland area. Specifically, a mean stock change factor was calculated as F = 0.82×1 + 0.18×1.14 = 1.03 because the mean percentages over the inventory period of unmanaged grazing land and improved grassland was 82% and 18%, respectively. Based on the IPCC soil type distribution for grassland shown in Figure 5, the mean national soil type distribution was: 85% HAC, 2% sandy soils, 9% spodic soil, and 4% wetland soils (i.e. gleysols). The mean SOC stock estimate for grassland was:

$$SOC_{grassland} = (0.85\times95 + 0.02\times71 + 0.09\times115 + 0.04\times 87)\ \text{Mg SOC ha}^{-1} = 95.9\ \text{Mg SOC ha}^{-1}.$$

Settlements: For settlements there is no default SOC stock estimate. The default methodology assumes no change in SOC stocks in settlement remaining settlements and it provides little information on appropriate estimates for land converted to or from settlements. Therefore, it was assumed that the SOC stock under settlements is 0 Mg C ha^{-1}. This may not be entirely true. In reality, the land-use category settlements also include vegetated areas such as parks, gardens, road sites and land under power lines, and these may have SOC stock closer to those of natural ecosystems. Further work is required to determine SOC stocks in settlement areas and to improve the accuracy of this estimate.

4.2.2. EMISSIONS AND REMOVALS FROM SOILS ON LAND CONVERTED TO CROPLAND OR GRASSLAND

Annual SOC stock changes were largest for forest land converted to cropland due to the size of the area under conversion. The conversion of settlements to cropland provided a modest level of C sequestration (Figure 8). The other land-use conversions caused losses off C. However, these emissions may be rather uncertain due to the Tier 1 methodology and the zero C stock assumption for settlement.

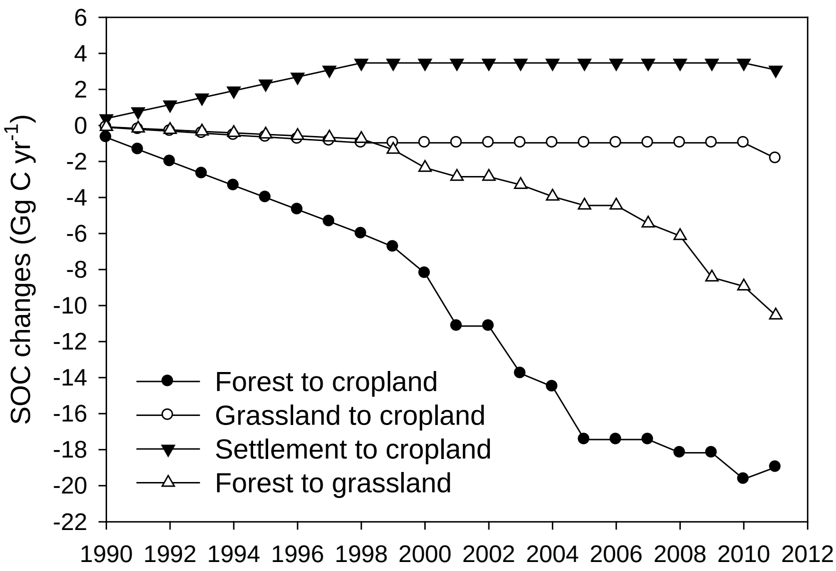

Figure 8: Soil organic carbon (SOC) changes using the Tier 1 method.

4.3. Dead organic matter

Dead organic matter (DOM) consists of litter and dead wood. In permanent cropland or grassland systems, this C pool can be considered negligible due to the small pools of dead wood and litter in these systems. However, on forest land converted to cropland or grassland, the decomposition of dead wood and plant litter on the forest floor will cause a loss of C and emissions of CO_2 should not be ignored.

4.3.1. METHODOLOGY

A Tier 2 method was used in the 2013 NIR submission where national mean C stocks of dead wood and litter were estimated for forest land. In accordance with the Tier 2 methodology, we assumed this C stock to decrease to zero over a period of 20 year as the dead organic matter stocks for cropland and grassland systems are assumed to be zero.

Model simulations were used to provide an estimate of the mean DOM stock in forest land. The Yasso07 model was used to simulate SOC stock changes for forest land remaining forest land in the 2013 NIR submission. Yasso07 simulates C turnover in separate pools that originate from non-woody, fine-woody and course-wood material. The C stocks of these three pools were added and assumed to represent the DOM pool. The mean C stock was estimated as the mean of the simulated C stocks for all the NFI plots of forest remaining forest from 1990 to 2011 (CPA, 2013). The national mean DOM stock estimate for forest was 22.47 Mg C ha^{-1}.

4.3.2. EMISSIONS FROM DEAD ORGANIC MATTER ON FOREST LAND CONVERTED TO CROPLAND OR GRASSLAND

Dead organic matter is a source of C emission of a similar size as the soil pool. Until 2008, estimated emission were larger for forest converted to cropland, but the last three years of the inventory period, the area of forest converted to grassland increased making the associated emissions larger (Figure 9).

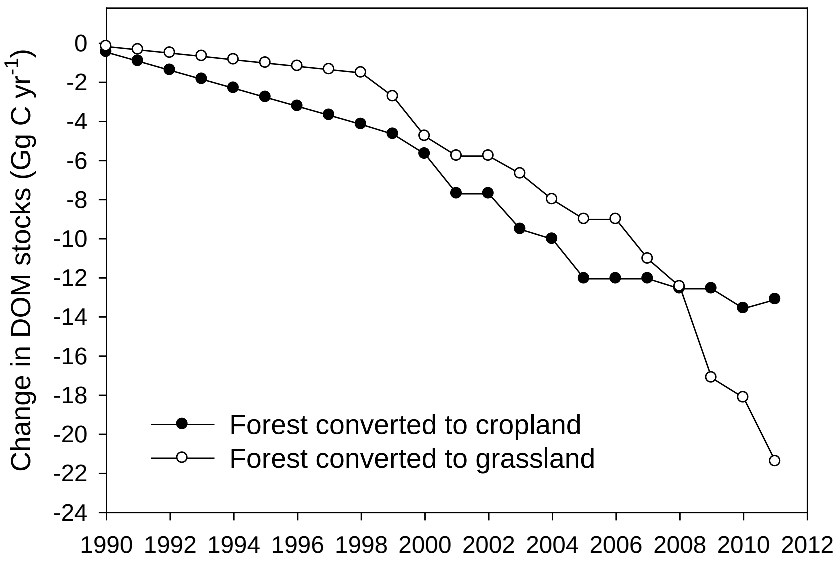

Figure 9: Change in the dead organic matter (DOM) pool (Gg C yr^{-1}) on forest land converted to cropland or grassland from 1990 to 2011.

These emissions are highly dependent on the accuracy of the Yasso07 simulation. Any changes and improvements made in the soil organic matter simulations for forest land can therefore alter these estimates as well. Due to the rather low Yasso07-estimated SOC stocks that are reported in the 2013 NIR submission, it is likely that emissions from DOM are underestimated. Further development is necessary to improve this methodology.

5. UNCERTAINTY ESTIMATION

5.1. General IPCC methodology for assessing uncertainty

In the UNFCCC reporting, it is required to provide uncertainty assessments with the emission estimates. Formally, the quantified uncertainties are used in the key category analysis, which is an analysis performed on the entire inventory including all sectors. The objective of the key category analysis is to determine the sink/source categories whose estimates have a significant influence on the total GHG inventory of a country in terms of the absolute level of the emissions and or the trend in the emissions (IPCC, 2003c). The uncertainties are not reported in the CRF tables. Nevertheless, it is important to provide uncertainty estimates in the NIR to indicate the level of confidence in an estimate. When possible it is recommended to provide quantitative uncertainties that are estimated by a method related to the tier level of the methodology used for the emission estimate. If a quantitative uncertainty value cannot be estimated for example based on sampling statistics, the uncertainty assessment may also be made qualitatively based on expert judgment. The IPCC guidelines provide uncertainty estimates for all the default emission or stock change factors for all the Tier 1 methods presented in this report (IPCC, 2006c; IPCC, 2006b).

For each land-use category, the total uncertainty is equal to the propagation of the uncertainty related to living biomass (U_{LB}), mineral soils(U_{MS}), organic soils(U_{OS}), and dead organic matter if relevant (U_{DOM}):

$$U_{CC} = \sqrt{{U_{LB}}^2 + {U_{MS}}^2 + {U_{OS}}^2 + {U_{DOM}}^2}$$

For each source category, the uncertainty is a combination of the uncertainties related to the emission factor or C stock change per hectare(U_C) and the area(U_A), which can be calculated by:

$$U = \sqrt{{U_C}^2 + {U_A}^2}$$

Depending on the methodology, the uncertainty of the activity data may be reflected only in the area or in both the area and the C change estimate. Generally, the uncertainty of the activity data may include errors in census returns as well as differences in definition between agencies, sampling design, and interpretation of samples.

5.2. Uncertainties in emission estimates for cropland and grassland

The area uncertainty estimates for cropland and grassland are larger than those for forest land due to the smaller number of sample plots represented in the NFI (CPA, 2013). The uncertainties of the area estimates for land converted to cropland or grassland are larger than the uncertainty for cropland and grassland in the remaining land-use category, which is also due to the smaller number of NFI sample plots (Table 9). For cropland and grassland source categories, the uncertainty of the C stock change estimate is between 75% and 231% with the largest ones being those for living biomass on grassland remaining grassland and land converted to grassland using a Tier 3 method and the smallest uncertainty being for living biomass on cropland remaining cropland where the Tier 1 method is used. This is counterintuitive because the higher Tier methods are supposed to have the lowest uncertainty. However, the uncertainty estimate for the Tier 3 is based on a small sample size, which may explain this difference. The total uncertainty assessment for the emissions estimated from organic soils is 100% (Table 9), which is based on expert judgment. We recommend improving this estimate given the key category status of the source category.

Table 9: Uncertainties (%) as 2×SE (standard error) for total C stock changes estimates for 2011. CC: cropland remaining cropland; LC: land converted to cropland; GG: grassland remaining grassland; LG: land converted to grassland. (Source: CPA, 2013)

Land-use class	Source category	Area uncertainty	C stock uncertainty	Total uncertainty
CC	Living biomass	~ 0%	75	75
CC	Mineral soils	6.7*	**	-
CC	Organic soils	6.7*	-	100
LC	Living biomass	42.4	-	-
LC	Mineral soils	42.4	90	99
GG	Living biomass	13.5	162.5	163.1
GG	Mineral soils	13.5	90.7	90.8
LG	Living biomass	40.4	228.1	231.7
LG	Mineral soils	40.4	90	98.5

* The uncertainty estimate for the area of cropland remaining cropland cannot be separated for organic and mineral soils.
** Quantitative uncertainty estimates have not yet been developed for the Tier 2 method using model-based stock change factors.

5.2.1. CROPLAND LIVING BIOMASS

Sources of uncertainty for the Tier 1 method for living biomass includes the degree of accuracy in the C accumulation and loss rates and the land-use activity data. The IPCC default uncertainty ranges for above-ground woody biomass accumulation in the temperate climate is ±75% based on expert judgment. Uncertainty of the activity data was estimated as approximately 0% according to Statistics Norway. The areas of orchards are used directly from the NAA/SSB data and are not related to the NFI database. The total uncertainty for emissions estimated for living biomass on cropland remaining cropland is therefore equal to the uncertainty of the C biomass accumulation per unit area (±75%).

In 2011, there were no recorded C losses in living biomass on forest land converted to cropland and no uncertainty is therefore reported. However, for other years with recorded loss, the uncertainty could be estimated using the equations shown below for grassland (section 5.2.3).

5.2.2. CROPLAND SOILS

Uncertainty related to emission estimates of mineral soils on cropland is quantifiable only for the area based on the NFI data. For the total area of cropland remaining cropland the uncertainty estimate was 6.7% for 2011 (CPA, 2013). However, this uncertainty estimate is based on an area that also includes organic soils. The area of organic soils is estimated by a different data source (see cropland – organic soil). It is, therefore, not possible to separate the uncertainties related to mineral and to organic soils. But a few assumptions can be made. The activity data of the areas per crop types and manure production that were collected through the subsidy application scheme administrated by NAA and compiled by SSB have small uncertainties. The data are based on a total national census. The NAA performs quality control on 5% of farms to determine if areas are provided correctly. These sample checks show very few errors. The area reported is based on a factor value multiplied by the last year's area, thus errors in previous years may accumulate. However, according to expert judgment given by SSB the uncertainty of the activity data is approximated to 0% (O. Rognstad, 2012. *pers. comm.*). The uncertainties related to the ICBM-estimated stock change factors and reference soil C stocks are certainly larger than zero. For the emission estimated from cultivated organic soils, the uncertainty estimate of the area and the emission factor was ±100% based on expert judgment.

Default uncertainty values of the SOC change estimate for land converted to cropland as estimated by the Tier 1 method are provided by IPCC. The uncertainty errors for the C stock and the area estimates can be propagated as

$$U_{LC\_soils} = \sqrt{U_C + U_A} = \sqrt{90^2 + 42^2} = 99\%.$$

5.2.3. GRASSLAND LIVING BIOMASS

The uncertainty of the C stock estimate of living tree biomass ($U(C_{LB})$) on grassland remaining grassland and land converted to grassland was estimated as

$$U(C_{LB}) = \sqrt{U(T)^2 + U(CF)^2}$$

where $U(T)$ is the uncertainty of the total biomass gain or loss estimate in percent of the estimate, which is given by

$$U(T) = \frac{2\sqrt{var(T)}}{T}100$$

and $U(CF) = 2\%$, which is the relative uncertainty in the carbon fraction (IPCC, 2003c). For 2011, the uncertainty in the biomass gains of trees on grassland remaining grassland was large (±162.5%) and for land converted to grassland the uncertainty estimate was ±200% for the gains and ±109.7% for the losses (aggregated uncertainty of 228.1%; Table 9). The uncertainties of the living biomass stocks were much larger than those estimated for the areas. For grassland remaining grassland the uncertainty of the area estimate was ±14% and for land converted to grassland the estimate was ±40% (Table 9).

5.2.4. GRASSLAND: SOILS

A Tier 1 uncertainty assessment was made considering both the uncertainty related to the C stock estimate (the stock change factors) and the activity data. First, we estimated the uncertainty of the SOC stock estimate (U_C) by propagating the uncertainty of the stock change factors and SOC reference stock. The errors of the stock change factors are provided in the 2006 guidelines (IPCC, 2006d). For the improved grassland management stock change factor, the uncertainty is ±11%. The stock change factor for nominally managed grassland has no associated uncertainty as it is the reference condition. The SOC reference has an uncertainty of ±90% according to Table 2.3 (IPCC, 2006a). Secondly, the uncertainty of the activity data was combined with that of the C stocks. The uncertainty in the activity data (U_A) covers both uncertainty in the estimates of the grassland management type (SSB data) and uncertainty in the area of grassland remaining grassland determined in the NFI. The first source of uncertainty, which is related to the determination of the type of grassland management system, was estimated to be close to zero by SSB (data from the national census described under cropland). The second source of uncertainty in the activity data, i.e. of the area estimate of grassland remaining grassland, was determined by the sample error and equal to 14%. The total uncertainty for grassland remaining grassland was estimated as:

$$U_{GG\_soils} = \sqrt{U_C + U_A} = \sqrt{11^2 + 90^2 + 14^2} = 90.8\%.$$

Similarly, the associated uncertainty with the SOC stock change in land converted to grassland can be estimated as:

$$U_{LG\_soils} = \sqrt{U_C + U_A} = \sqrt{90^2 + 40^2} = 98.5\%.$$

6. CONCLUSION

This report provides a comprehensive documentation of new methodologies that were implemented in the 2013 NIR submission and an evaluation of the previously-used methods for cropland and grassland. Throughout the evaluation of the 2011 and 2012 NIR submission, it was found necessary to improve several methodologies.

Especially the estimation method for C emissions from soils needed a replacement. For cropland remaining cropland and grassland remaining grassland soil C emissions were previously estimated with an erosion-based emission factor. We conclude that the assumption that erosion rates can be used as an indicator for national SOC stock change estimates is not uniformly supported in scientific literature. The old method based on this assumption was therefore replaced by IPCC Tier 1 and 2 methods that apply stock change factors and soil C reference stocks. Methodological changes were made to estimate emissions from soil organic matter on lands in conversion. We describe the Tier 1 method in detail that was applied in the 2013 NIR submission. The Tier 1 method facilitates emission estimates from changes in soil C caused by land-use change between all IPCC land-use classes.

The methodologies used for living biomass prior to the 2013 NIR submission were satisfactory and in accordance with good practice guidance (IPCC, 2003b) and the 2006 guidelines (IPCC, 2006a). Although changes were made in the area estimation (NFI area estimates were quality checked) and in the assumptions for orchards (lands where fruit trees are felled is still considered cropland), the methods used for C stock change in living biomass were suitable.

It is important to apply transparent and comprehensive methods in the inventory reporting in order to facilitate the review process and to enable better international emission comparisons. Thus, using the IPCC methodologies as strictly as possible should be a goal for inventory reporters when possible.

Further method development suggested here includes improving the accuracy and preciseness of C stock change estimates in soils for cropland and grassland. We find the best way to achieve this would be to:

1) Improve the area estimates of cultivated organic soils for both cropland and grassland land-use categories.
2) Implement a higher tiered method (Tier 2 or 3) for SOC change estimates for land-use changes. (This is especially urgent if it is to be included in the last reporting year of the first commitment period of the Kyoto Protocol reporting in 2014.)
3) Test and implement a Tier 3 method for estimating SOC changes on cropland remaining cropland by dynamic simulations using the ICBM.
4) Evaluate and implement a Tier 2 method for estimates of SOC changes on grassland remaining grassland using soil C measurements or modeling.

In conclusion, our methodological study describes several approaches to estimate C stock changes on cropland and grassland and evaluates their compliance with the IPCC guidelines. The alternative methods presented in this report assist to better fulfill the completeness and other reporting requirements for national GHG inventories decided by the COP (Conference of Parties under the convention) and the CMP (Conference Meeting of Parties to the Kyoto Protocol) under the UNFCCC.

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