CHAPTER 5

CROPLAND

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5.1 INTRODUCTION

This section provides a tiered methodology for estimating and reporting greenhouse gas emissions from croplands. Cropland includes arable and tillable land, rice fields, and agroforestry systems where the vegetation structure falls below the thresholds used for the Forest Land category, and is not expected to exceed those thresholds at a later time. Cropland includes all annual and perennial crops as well as temporary fallow land (i.e., land set at rest for one or several years before being cultivated again). Annual crops include cereals, oils seeds, vegetables, root crops and forages. Perennial crops include trees and shrubs, in combination with herbaceous crops (e.g., agroforestry) or as orchards, vineyards and plantations such as cocoa, coffee, tea, oil palm, coconut, rubber trees, and bananas, except where these lands meet the criteria for categorisation as Forest Land. Arable land which is normally used for cultivation of annual crops but which is temporarily used for forage crops or grazing as part of an annual crop-pasture rotation (mixed system) is included under cropland.

The amount of carbon stored in and emitted or removed from permanent cropland depends on crop type, management practices, and soil and climate variables. For example, annual crops (cereals, vegetables) are harvested each year, so there is no long-term storage of carbon in biomass. However, perennial woody vegetation in orchards, vineyards, and agroforestry systems can store significant carbon in long-lived biomass, the amount depending on species type and cultivar, density, growth rates, and harvesting and pruning practices. Carbon stocks in soils can be significant and changes in stocks can occur in conjunction with soil properties and management practices, including crop type and rotation, tillage, drainage, residue management and organic amendments. Burning of crop residue produces significant non-CO_2 greenhouse gases and the calculation methods are provided.

There is separate guidance for *Cropland Remaining Cropland* (CC) and *Land Converted to Cropland* (LC) because of the difference in carbon dynamics. Land-use conversions to Cropland from Forest Land, Grassland and Wetlands usually result in a net loss of carbon from biomass and soils as well as N_2O to the atmosphere. However, Cropland established on previously sparsely vegetated or highly disturbed lands (e.g., mined lands) can result in a net gain in both biomass and soil carbon. Some changes, especially those dealing with soil carbon, may take place in periods of time longer than one year. The guidance covers the carbon pools shown in Box 5.1.

The term land-use conversion refers only to lands coming from one type of use into another. In cases where existing perennial cropland is replanted to the same or different crops, the land use remains Cropland; therefore, the carbon stock changes should be estimated using the methods for *Cropland Remaining Cropland*, as described in Section 5.2 below.

BOX 5.1
RELEVANT CARBON POOLS FOR CROPLAND

Biomass

- Above-ground biomass
- Below-ground biomass

Dead organic matter

- Dead wood
- Litter

Soils (soil organic matter)

The new features of the *2006 IPCC Guidelines* relative to *1996 IPCC Guidelines* are the following:

- the whole Cropland section is new;
- biomass carbon and soil carbon are in the same section;
- methane emissions from rice are included in the Cropland category;
- non-CO_2 gas emissions from biomass burning (*Cropland Remaining Cropland* and *Land Converted to Cropland*) are also included in the Cropland chapter; and
- default values are provided for biomass on Cropland and agroforestry areas.

5.2 CROPLAND REMAINING CROPLAND

This section provides guidelines on greenhouse gas inventory for croplands that have not undergone any land-use conversion for a period of at least 20 years as a default period [1]. Section 5.3 provides guidelines on *Land Converted to Cropland* more recently than this. The annual greenhouse gas emissions and removals from *Cropland Remaining Cropland* include:

- Estimates of annual change in C stocks from all C pools and sources; and
- Estimates of annual emission of non-CO_2 gases from all pools and sources.

The changes in carbon stocks in *Cropland Remaining Cropland* are estimated using Equation 2.3.

5.2.1 Biomass

5.2.1.1 CHOICE OF METHODS

Carbon can be stored in the biomass of croplands that contain perennial woody vegetation including, but not limited to, monocultures such as coffee, oil palm, coconut, rubber plantations, fruit and nut orchards, and polycultures such as agroforestry systems. The default methodology for estimating carbon stock changes in woody biomass is provided in Chapter 2, Section 2.2.1. This section elaborates this methodology with respect to estimating changes in carbon stocks in biomass in *Cropland Remaining Cropland*.

The change in biomass is only estimated for perennial woody crops. For annual crops, increase in biomass stocks in a single year is assumed equal to biomass losses from harvest and mortality in that same year - thus there is no net accumulation of biomass carbon stocks.

Changes in carbon in cropland biomass (ΔC_{CC_B}) may be estimated from either: (a) annual rates of biomass gain and loss (Chapter 2, Equation 2.7) or (b) carbon stocks at two points in time (Chapter 2, Equation 2.8). The first approach (gain-loss method) provides the default Tier 1 method and can also be used at Tier 2 or 3 with refinements described below. The second approach (the stock-difference method) applies either at Tier 2 or Tier 3, but not Tier 1. It is *good practice* to improve inventories by using the highest feasible tier given national circumstances. It is *good practice* for countries to use a Tier 2 or Tier 3 method if carbon emissions and removals in *Cropland Remaining Cropland* is a key category and if the sub-category of biomass is considered significant. It is *good practice* for countries to use the decision tree in Figure 2.2 in Chapter 2 to identify the appropriate tier to estimate changes in carbon stocks in biomass.

Tier 1

The default method is to multiply the area of perennial woody cropland by a net estimate of biomass accumulation from growth and subtract losses associated with harvest or gathering or disturbance (according to Equation 2.7 in Chapter 2). Losses are estimated by multiplying a carbon stock value by the area of cropland on which perennial woody crops are harvested.

Default Tier 1 assumptions are: all carbon in perennial woody biomass removed (e.g., biomass cleared and replanted with a different crop) is emitted in the year of removal; and perennial woody crops accumulate carbon for an amount of time equal to a nominal harvest/maturity cycle. The latter assumption implies that perennial woody crops accumulate biomass for a finite period until they are removed through harvest or reach a steady state where there is no net accumulation of carbon in biomass because growth rates have slowed and incremental gains from growth are offset by losses from natural mortality, pruning or other losses.

Under Tier 1, default factors shown in Table 5.1, are applied to nationally derived estimates of land areas.

Tier 2

Two methods can be used for Tier 2 estimation of changes in biomass. Method 1 (also called the **Gain-Loss Method**) requires the biomass carbon loss to be subtracted from the biomass carbon increment for the reporting year (Chapter 2, Equation 2.7). Method 2 (also called the **Stock-Difference Method**) requires biomass carbon stock inventories for a given land-use area at two points in time (Chapter 2, Equation 2.8).

A Tier 2 estimate, in contrast, will generally develop estimates for the major woody crop types by climate zones, using country-specific carbon accumulation rates and stock losses where possible or country-specific estimates of carbon stocks at two points in time. Under Tier 2, carbon stock changes are estimated for above-ground and

[1] Countries using higher tier methods may use different time periods depending on the time taken for carbon stocks to equilibrate after change in land use.

below-ground biomass in perennial woody vegetation. Tier 2 methods involve country-specific or region-specific estimates of biomass stocks by major cropland types and management system, and estimates of stock change as a function of major management system (e.g., dominant crop, productivity management). To the extent possible, it is *good practice* for countries to incorporate changes in perennial crop or tree biomass using country-specific or region-specific data. Where data are missing, default data may be used.

Tier 3

A Tier 3 estimate will use a highly disaggregated Tier 2 approach or a country-specific method involving process modelling and/or detailed measurement. Tier 3 involves inventory systems using statistically-based sampling of carbon stocks over time and/or process models, stratified by climate, cropland type and management regime. For example, validated species-specific growth models that incorporate management effects such as harvesting and fertilization, with corresponding data on management activities, can be used to estimate net changes in cropland biomass carbon stocks over time. Models, perhaps accompanied by measurements like those in forest inventories, can be used to estimate stock changes and extrapolate to entire cropland areas, as in Tier 2.

Key criteria in selecting appropriate models are that they are capable of representing all of the management practices that are represented in the activity data. It is critical that the model be validated with independent observations from country-specific or region-specific field locations that are representative of climate, soil and cropland management systems in the country.

5.2.1.2 CHOICE OF EMISSION FACTORS

Emission and removal factors required to estimate the changes in carbon stocks include (a) annual biomass accumulation or growth rate, and (b) biomass loss factors which are influenced by such activities as removal (harvesting), fuelwood gathering and disturbance.

Above-ground woody biomass growth rate

Tier 1

Tables 5.1 to 5.3 provide estimates of biomass stocks and biomass growth rates and losses for major climatic regions and agricultural systems. However, given the large variation in cropping systems, incorporating trees or tree crops, it is *good practice* to seek national data on above-ground woody biomass growth rate.

Tier 2

Annual woody biomass growth rate data can be, at a finer or disaggregated scale, based on national data sources for different cropping and agroforestry systems. Rates of change in annual woody biomass growth rate should be estimated in response to changes in specific management/land-use activities (e.g., fertilization, harvesting, thinning). Results from field research should be compared to estimates of biomass growth from other sources to verify that they are within documented ranges. It is important, in deriving estimates of biomass accumulation rates, to recognize that biomass growth rates will occur primarily during the first 20 years following changes in management, after which time the rates will tend towards a new steady-state level with little or no change occurring unless further changes in management conditions occur.

Tier 3

For Tier 3, highly disaggregated factors for biomass accumulation are needed. These may include categorisation of species, specific for growth models that incorporate management effects such as harvesting and fertilization. Measurement of above-ground biomass, similar to forest inventory with periodic measurement of above-ground biomass accumulation, is necessary.

TABLE 5.1
DEFAULT COEFFICIENTS FOR ABOVE-GROUND WOODY BIOMASS AND HARVEST CYCLES IN CROPPING SYSTEMS CONTAINING PERENNIAL SPECIES

Climate region	Above-ground biomass carbon stock at harvest (tonnes C ha^{-1})	Harvest /Maturity cycle (yr)	Biomass accumulation rate (G) (tonnes C ha^{-1} yr^{-1})	Biomass carbon loss (L) (tonnes C ha^{-1} yr^{-1})	Error range[1]
Temperate (all moisture regimes)	63	30	2.1	63	± 75%
Tropical, dry	9	5	1.8	9	± 75%
Tropical, moist	21	8	2.6	21	± 75%
Tropical, wet	50	5	10.0	50	± 75%

Note: Values are derived from the literature survey and synthesis published by Schroeder (1994).

[1] Represents a nominal estimate of error, equivalent to two times standard deviation, as a percentage of the mean.

TABLE 5.2
POTENTIAL C STORAGE FOR AGROFORESTRY SYSTEMS IN DIFFERENT ECOREGIONS OF THE WORLD

Region	Eco-region	System	Above-ground biomass (tonnes ha^{-1})	Range (tonnes ha^{-1})
Africa	Humid tropical high	Agrosilvicultural	41.0	29 - 53
S America	Humid tropical low	Agrosilvicultural	70.5	39 - 102
S America	Dry lowlands	Agrosilvicultural	117.0	39 - 195
SE Asia	Humid tropical	Agrosilvicultural	120.0	12 - 228
SE Asia	Dry lowlands	Agrosilvicultural	75.0	68 - 81
Australia	Humid topical	Silvopastoral	39.5	28 - 51
N America	Humid tropical high	Silvopastoral	143.5	133 - 154
N America	Humid tropical low	Silvopastoral	151.0	104 - 198
N America	Dry lowlands	Silvopastoral	132.5	90 - 175
N Asia	Humid tropical low	Silvopastoral	16.5	15 - 18

Source: Albrecht and Kandji, 2003

TABLE 5.3
DEFAULT ABOVE-GROUND BIOMASS FOR VARIOUS TYPES OF PERENNIAL CROPLANDS (TONNES HA^{-1})

Cropland type	Region	Above-ground biomass	Range	Error	References
Oil Palm	SE Asia	136.0	62 - 202	78	
Mature rubber	SE Asia	178.0		90	Palm *et al.*, 1999
Young rubber	SE Asia	48.0	16 - 80		Wasrin *et al.*, 2000
Young cinnamon (7 years)	SE Asia	68.0		47	Siregar & Gintings, 2000
Coconut	SE Asia	196.0			Lasco *et al.*, 2002
Improved fallow					
2-year fallow	E Africa	35.0	27 - 44	40	Albrecht and Kandji, 2003
1-year fallow	E Africa	12.0	7 - 21	89	Albrecht and Kandji, 2003
6-year fallow (average)	SE Asia	16.0	4 - 64		Lasco and Suson, 1999
Alley cropping	SE Asia	2.9	1.5 - 4.5	105	Lasco *et al.*, 2001
Multistorey system					
Jungle rubber	SE Asia	304.0		17	Tomich *et al.*, 1998
Gmelina-cacao	SE Asia	116.0		53	Lasco *et al.*, 2001

Below-ground biomass accumulation

Tier 1

The default assumption is that there is no change in below-ground biomass of perennial trees in agricultural systems. Default values for below-ground biomass for agricultural systems are not available.

Tier 2

This includes the use of actually measured below-ground biomass data from perennial woody vegetation. Estimating below-ground biomass accumulation is recommended for Tier 2 calculation. Root-to-shoot ratios show wide ranges in values at both individual species (e.g., Anderson *et al.*, 1972*)* and community scales (e.g., Jackson *et al.*, 1996; Cairns *et al.*, 1997*)*. Limited data is available for below ground biomass thus, as far as possible, empirically-derived root-to-shoot ratios specific to a region or vegetation type should be used.

Tier 3

This includes the use of data from field studies identical to forest inventories and modelling studies, if stock difference method is adopted.

Biomass losses from removal, fuelwood and disturbance

Tier 1

The default assumption is that all biomass lost is assumed to be emitted in the same year. Biomass removal, fuelwood gathering and disturbance loss data from cropland source are not available. FAO provides total roundwood and fuelwood consumption data, but not separated by source (e.g., Cropland, Forest Land, etc.). It is recognized that statistics on fuelwood are extremely poor and uncertain worldwide. Default removal and fuelwood gathering statistics (discussed in Chapter 4, Section 4.2) may include biomass coming from cropland such as when firewood is harvested from home gardens. Thus, it is necessary to ensure no double counting of losses occurs. If no data are available for roundwood or fuelwood sources from Cropland, the default approach will include losses in Forest Land (Section 4.2) and will exclude losses from Cropland.

Tiers 2 and 3

National level data at a finer scale, based on inventory studies or production and consumption studies according to different sources, including agricultural systems, can be used to estimate biomass loss. These can be obtained through a variety of methods, including estimating density (crown coverage) of woody vegetation from air photos (or high resolution satellite imagery) and ground-based measurement plots. Species composition, density and above-ground vs. below-ground biomass can vary widely for different cropland types and conditions and thus it may be most efficient to stratify sampling and survey plots by cropland types. General guidance on survey and sampling techniques for biomass inventories is given in Chapter 3, Annex 3A.3.

5.2.1.3 CHOICE OF ACTIVITY DATA

Activity data in this section refer to estimates of land areas of growing stock and harvested land with perennial woody crops. The area data are estimated using the approaches described in Chapter 3. They should be regarded as strata within the total cropland area (to keep land-use data consistent) and should be disaggregated depending on the tier used and availability of growth and loss factors. Examples of Cropland subcategories are given in Table 5.4.

TABLE 5.4
EXAMPLES OF PERENNIAL CROPLAND SUBCATEGORIES WHICH A COUNTRY MAY HAVE

Broad subcategories	Specific subcategories
Fruit orchards	Mango, Citrus, Apple
Plantation crops	Rubber, Coconut, Oil palm, Coffee, Cacao
Agroforestry systems	Hedgerow cropping (alley cropping), Improved fallow, Multi-storey systems, Home gardens, Boundary planting, Windbreaks

Tier 1

Under Tier 1, annual or periodic surveys are used in conjunction with the approaches outlined in Chapter 3 to estimate the average annual area of established perennial woody crops and the average annual area of perennial woody crops that are harvested or removed. The area estimates are further sub-divided into general climate regions or soil types to match the default biomass gain and loss values. Under Tier 1 calculations, international statistics such as FAO databases, and other sources can be used to estimate the area of land under perennial woody crops.

Tier 2

Under Tier 2, more detailed annual or periodic surveys are used to estimate the areas of land in different classes of perennial woody biomass crops. Areas are further classified into relevant sub categories such that all major combinations of perennial woody crop types and climatic regions are represented with each area estimate. These area estimates must match any country-specific biomass carbon increment and loss values developed for the Tier 2 method. If country-specific finer resolution data are only partially available, countries are encouraged to extrapolate to the entire land base of perennial woody crops using sound assumptions from best available knowledge.

Tier 3

Tier 3 requires high-resolution activity data disaggregated at sub-national to fine grid scales. Similar to Tier 2, land area is classified into specific types of perennial woody crops by major climate and soil categories and other potentially important regional variables (e.g., regional patterns of management practices). Furthermore, it is *good practice* to relate spatially explicit area estimates with local estimates of biomass increment, loss rates, and management practices to improve the accuracy of estimates.

5.2.1.4 CALCULATION STEPS FOR TIER 1 AND TIER 2

Summary of steps for estimating change in carbon stocks in biomass in Cropland Remaining Cropland (ΔC_B) using the Tier 1 and Tier 2 methods

Using the worksheets for Cropland (see Annex 1 –AFOLU Worksheets), calculate the change in biomass carbon stocks of *Cropland Remaining Cropland*:

Step 1: Enter the subcategories of Cropland for the reporting year

Typically, there are various types of Cropland with woody perennial cover in a country with varying biomass stocks and increments. Examples of these are: fruit orchards (e.g., mango, citrus), agricultural plantations (e.g., coconut, rubber) and agroforestry farms.

Step 2: For each sub-category, enter the annual area of Cropland with perennial woody biomass

The area (A) in hectares of each sub-category of Cropland can usually be obtained from national land-use agencies, Ministry of Agriculture, and Ministry of Natural Resources. Possible sources of data include: satellite images, aerial photography and land-based surveys, and FAO database.

Step 3: For each sub-category, enter the mean annual carbon stocks in the biomass accumulation (in tonnes C ha yr^{-1}) of perennial woody biomass

The annual growth rates (ΔC_G) for each sub-category of Cropland, from the biomass accumulation rates G in Table 5.1, are entered in the appropriate column of worksheets.

Step 4: For each sub-category, enter the annual carbon stocks in biomass losses (in tonnes C ha yr^{-1})

If there is harvesting, the amount of carbon stocks from the biomass harvested (ΔC_L) is entered in the appropriate column. This can be estimated by multiplying the default above woody above ground biomass for various croplands in Table 5.3 by the default carbon density of 0.5 tonne C/tonne biomass.

Step 5: Calculate the annual change of carbon stocks in biomass for each sub-category

The annual change of carbon stocks in biomass (ΔC_B) is calculated using Equation 2.7 in Chapter 2.

Step 6: Calculate the total change in carbon stocks (ΔC_B) by adding up all the values of the subcategory estimates.

Example 1: In the inventory year, 90,000 hectares of perennial woody crops are cultivated in a tropical moist environment, while 10,000 ha are subjected to harvesting. The immature perennial woody cropland area accumulates carbon at a rate of approximately 2.6 tonnes of above ground C ha^{-1} yr^{-1}. The area harvested looses all carbon in biomass stocks in the year of removal. Default carbon stock losses for a tropical moist perennial woody cropland are 21 tonnes C ha^{-1} yr^{-1}. From these values, an estimated 234,000 tonnes C accumulates per year and 210,000 tonnes C are lost. Using Equation 2.7 in Chapter 2, the net change in carbon stocks (above-ground) in the tropical moist environment are 24,000 tonnes C yr^{-1}.

5.2.1.5 UNCERTAINTY ASSESSMENT

The following discussion provides guidance on approaches for assessing uncertainty associated with estimates of biomass carbon for each tier method.

Tier 1

The sources of uncertainty when using the Tier 1 method include the degree of accuracy in land area estimates (see Chapter 3) and in the default biomass carbon increment and loss rates. Uncertainty is likely to be low (<10%) for estimates of area under different cropping systems since most countries annually estimate cropland area using reliable methods. A published compilation of research on carbon stocks in agroforestry systems was used to derive the default data provided in Table 5.1 (Schroeder, 1994). While defaults were derived from multiple studies, their associated uncertainty ranges were not included in the publication. Therefore, a default uncertainty level of $\pm$75% of the parameter value has been assigned based on expert judgement. This information can be used, with a measure of uncertainty in area estimates from Chapter 3 of this Report, to assess the uncertainty in estimates of carbon emissions and removals in Cropland biomass using the Tier 1 methodology. Guidance on uncertainty analysis is given in Volume 1, Chapter 3.

Tier 2

The Tier 2 method will reduce overall uncertainty because country-specific emission and removal factors rates should provide more accurate estimates of carbon increment and loss for crop systems and climatic regions within national boundaries. It is *good practice* to calculate error estimates (i.e., standard deviations, standard error, or ranges) for country-specific carbon increment rates and to use these variables in a basic uncertainty assessment. It is *good practice* for countries to assess error ranges in country-specific coefficients and compare them to those of default carbon accumulation coefficients. If country-specific rates have equal or greater error ranges than default coefficients, then it is *good practice* to use a Tier 1 approach and to further refine country-specific rates with more field measurements.

Tier 2 approaches may also use finer resolution activity data, such as area estimates for different climatic regions or for specific cropping systems within national boundaries. The finer-resolution data will further reduce uncertainty levels when associated with biomass carbon increment factors defined for those finer-scale land bases (e.g., when area of coffee plantations is multiplied by a coffee plantation coefficient, rather than by a generic agroforestry default).

Tier 3

Tier 3 approaches will provide the greatest level of certainty relative to Tiers 1 and 2 approaches. It is *good practice* to calculate standard deviations, standard errors, or ranges for all country-defined biomass increment and loss rates. It is *good practice* for countries to develop probability density functions for model parameters to use in Monte Carlo simulations. The uncertainty, particularly with respect to area estimates, is likely to be less or absent for cropping systems.

5.2.2 Dead organic matter

Methods for estimating carbon stock changes associated with dead organic matter pools are presented in this section for *Cropland Remaining Cropland* (CC). Methods are provided for two types of dead organic matter pools: 1) dead wood and 2) litter. Chapter 1of this report provides detailed definitions of these pools.

Dead wood is a diverse pool with many practical problems for measuring in the field and associated uncertainties about rates of transfer to litter, soil, or emissions to the atmosphere. Carbon in dead wood is highly variable between stands across the landscape. Amounts of dead wood depend on the time of last disturbance, the amount of input (mortality) at the time of the disturbance, natural mortality rates, decay rates, and management.

Litter accumulation is a function of the annual amount of litterfall, which includes all leaves, twigs and small branches, hay, fruits, flowers, and bark, minus the annual rate of decomposition. The litter mass is also influenced by the time since the last disturbance, and the type of disturbance. Management such as wood and grass harvesting, burning, and grazing dramatically alter litter properties, but there are few studies clearly documenting the effects of management on litter carbon.

In general, croplands will have little or no dead wood, crop residues or litter, with the exception of agroforestry systems which may be accounted under either Cropland or Forest Land, depending upon definitions adopted by countries for reporting.

5.2.2.1 CHOICE OF METHOD

The decision tree in Chapter 2, Figure 2.3 provides assistance in the selection of the appropriate tier level for the implementation of estimation procedures. Estimation of changes in carbon stocks in DOM requires an estimate of changes in stocks of dead wood and changes in litter stocks (refer to Equation 2.17 in Chapter 2).

Each of the DOM pools (dead wood and litter) is to be treated separately, but the method for determining changes in each pool is the same.

Tier 1

The Tier 1 method assumes that the dead wood and litter stocks are not present in Cropland or are at equilibrium as in agroforestry systems and orchards. Thus, there is no need to estimate the carbon stock changes for these pools.

Tiers 2 and 3

Tiers 2 and 3 allow for calculation of changes in dead wood and litter carbon due to management practices. Two methods are suggested for estimating the carbon stock change in DOM.

Method 1 (Also called the **Gain-Loss Method**, Equation 2.18 in Chapter 2): Method 1 involves estimating the area of cropland management categories and the average annual transfer into and out of dead wood and litter stocks. This requires an estimate of area under *Cropland Remaining Cropland* according to: i) different climate or cropland types; ii) management regime, or other factors significantly affecting dead wood and litter carbon pools; and iii) the quantity of biomass transferred into dead wood and litter stocks as well as the quantity of biomass transferred out of the dead wood and litter stocks on per hectare basis according to different cropland types.

Method 2 (Also called the **Stock-Difference Method**, Equation 2.19 in Chapter 2): Method 2 involves estimating the area of cropland and the dead wood and litter stocks at two periods of time, t_1 and t_2. The dead wood and litter stock changes for the inventory year are obtained by dividing the stock changes by the period (years) between two measurements. Method 2 is feasible for countries which have periodic inventories. This method is more suitable for countries adopting Tier 3 methods. Tier 3 methods are used where countries have country-specific emission factors and national data. Country-defined methodology may be based on detailed inventories of permanent sample plots for their croplands and/or models.

5.2.2.2 CHOICE OF EMISSION/REMOVAL FACTORS

Carbon fraction: The carbon fraction of dead wood and litter is variable and depends on the stage of decomposition. Wood is much less variable than litter and a value of 0.50 tonne C (tonne d.m.)$^{-1}$ can be used for the carbon fraction.

Tier 1

The assumption in Tier 1 is that the DOM carbon stocks in all *Cropland Remaining Cropland* are insignificant or are not changing and therefore no emission/removal factors and activity data are needed. Countries experiencing significant changes in cropland management or disturbances that are likely to affect DOM pools are encouraged to develop domestic data to quantify this impact and report it under Tier 2 or 3 methodologies.

Tier 2

It is *good practice* to use country-level data on DOM for different Cropland categories, in combination with default values, if country-specific or regional values are not available for some Cropland categories. Country-specific values for the transfer of carbon from live trees that are harvested to harvest residues, and decomposition rates (in the case of Method 1) or the net change in DOM pools (in the case of Method 2), can be derived from country-specific data, taking into account the Cropland type, the rate of biomass utilization, harvesting practices, and the amount of damaged vegetation during harvesting operations.

Tier 3

For Tier 3, countries should develop their own methodologies and parameters for estimating changes in DOM. These methodologies may be derived from Method 1 or 2 specified above, or may be based on other approaches. The method used needs to be clearly documented.

National level disaggregated DOM carbon estimates should be determined as part of a national Cropland inventory, national level models, or from a dedicated greenhouse gas inventory programme, with periodic sampling according to the principles set out in Chapter 3, Annex 3A.3. Inventory data can be coupled with modelling studies to capture the dynamics of all Cropland carbon pools.

5.2.2.3 CHOICE OF ACTIVITY DATA

Activity data consist of areas of *Cropland Remaining Cropland* summarised by major cropland types and management practices. Total Cropland areas should be consistent with those reported under other sections of this chapter, notably under the biomass section of *Cropland Remaining Cropland*. Tying this information to national soils, climate, vegetation, and other geophysical data makes it easier to assess changes in DOM.

5.2.2.4 CALCULATION STEPS FOR TIERS 1 AND 2

The following summarizes steps for estimating change in DOM carbon stocks

Tier 1
Activity data are not needed as the DOM pool is assumed to be stable.

Tier 2 (Gain-Loss Method) – Equation 2.18 in Chapter 2
Each of the DOM pools (dead wood and litter) is to be treated separately, but the method for each pool is the same.

Step 1: Determine the categories or Cropland types and management systems to be used in this assessment and the representative area. Area data should be obtained using the methods described in Chapter 3.

Step 2: Determine the net change in DOM stocks for each category. Identify values from inventories or scientific studies for the average inputs and outputs of dead wood or litter for each category. Countries should use locally available data for inputs and outputs from these pools. Calculate the net change in the DOM pools by subtracting the outputs from the inputs. Negative values indicate a net decrease in the stock.

Step 3: Determine the net change in DOM carbon stocks for each category based on Step 2. Multiply the change in DOM stocks by the carbon fraction of the dead wood and litter to determine the net change in dead wood carbon stocks. The default value is 0.50 tonne C (tonne d.m.)$^{-1}$ for dead wood and 0.40 tonne C (tonne d.m.)$^{-1}$ for litter.

Step 4: Determine the total change in the DOM carbon pools for each category by multiplying the representative area of each category by the net change in DOM carbon stocks for that category.

Step 5: Determine the total change in carbon stocks in DOM by taking the sum of the total changes in DOM across all categories.

Tier 2 (Stock-Difference Method) – Equation 2.19 in Chapter 2
Each of the DOM pools is to be treated separately, but the method for each pool is the same.

Step 1: Determine the categories to be used in this assessment and the representative area as described for Method 1.

Step 2: Determine the net change in DOM stocks for each category. From the inventory data, identify the inventory time interval, the average stock of DOM at the initial inventory (t_1), and the average stock of DOM at the final inventory (t_2). Use these figures to calculate the net annual change in DOM stocks by subtracting the DOM stock at t_1 from the DOM stock at t_2 and dividing this difference by the time interval. A negative value indicates a decrease in the DOM stock.

Step 3: Determine the net change in DOM carbon stocks for each category. Determine the net change in DOM carbon stocks by multiplying the net change in DOM stocks for each category by the carbon fraction of the DOM. The default value is 0.50 tonne C (tonne d.m.)$^{-1}$ for dead wood and 0.40 tonne C (tonne d.m.)$^{-1}$ for litter. A Tier 3 approach requires country-specific or ecosystem-specific expansion factors. A Tier 2 approach can use national level default expansion factors.

Step 4: Determine the total change in the DOM carbon pool for each activity category by multiplying the representative area of each activity category by the net change in DOM carbon stocks for that category.

Step 5: Determine the total change in carbon stocks in DOM by taking the sum of the total changes in DOM across all activity categories.

5.2.2.5 UNCERTAINTY ASSESSMENT

Uncertainty estimation is not required at Tier 1 since the DOM stocks are assumed to be stable. For Tiers 2 and 3, area data and estimates of uncertainty should be obtained using the methods in Chapter 3. Carbon accumulation and loss factors should be assessed locally.

5.2.3 Soil carbon

Cropland management modifies soil C stocks to varying degrees depending on how specific practices influence C input and output from the soil system (Paustian *et al*., 1997; Bruce *et al*., 1999; Ogle *et al*., 2005). The main management practices that affect soil C stocks in croplands are the type of residue management, tillage management, fertilizer management (both mineral fertilizers and organic amendments), choice of crop and intensity of cropping management (e.g., continuous cropping versus cropping rotations with periods of bare fallow), irrigation management, and mixed systems with cropping and pasture or hay in rotating sequences. In addition, drainage and cultivation of organic soils reduces soil C stocks (Armentano and Menges, 1986).

General information and guidance for estimating changes in soil C stocks are found in Section 2.3.3 of Chapter 2 (including equations). That section should be read before proceeding with specific guidelines dealing with Cropland soil C stocks. The total change in soil C stocks for Cropland is estimated using Equation 2.24 (Chapter 2), which combines the change in soil organic C stocks for mineral soils and organic soils; and stock changes associated with soil inorganic C pools (Tier 3 only). This section provides specific guidance for estimating soil organic C stock changes. Soil inorganic C is fully covered by Section 2.3.3.1.

To account for changes in soil C stocks associated with *Cropland Remaining Cropland*, countries need at a minimum, estimates of the Cropland area at the beginning and end of the inventory time period. If land-use and management data are limited, aggregate data, such as FAO statistics on Cropland, can be used as a starting point, along with expert knowledge about the approximate distribution of land management systems (e.g., medium, low and high input cropping systems, etc.). Cropland management classes must be stratified according to climate regions and major soil types, which can either be based on default or country-specific classifications. This can be accomplished with overlays of land use on suitable climate and soil maps.

5.2.3.1 CHOICE OF METHOD

Inventories can be developed using a Tier 1, 2, or 3 approach, with each successive Tier requiring more detail and resources than the previous one. It is also possible that countries will use different tiers to prepare estimates for the separate subcategories of soil C (i.e., soil organic C stocks changes in mineral soils and organic soils, and stock changes associated with soil inorganic C pools). Decision trees are provided for mineral soils (Figure 2.4) and organic soils (Figure 2.5) in Section 2.3.3.1 (Chapter 2) to assist inventory compilers with selection of the appropriate tier for their soil C inventory.

Mineral soils

Tier 1

For mineral soils, the estimation method is based on changes in soil organic C stocks over a finite period following changes in management that impact soil organic C. Equation 2.25 (Chapter 2) is used to estimate change in soil organic C stocks in mineral soils by subtracting the C stock in the last year of an inventory time period (SOC_0) from the C stock at the beginning of the inventory time period ($SOC_{(0-T)}$) and dividing by the time dependence of the stock change factors (D). In practice, country-specific data on land use and management must be obtained and classified into appropriate land management systems (e.g., high, medium and low input cropping), including tillage management, and then stratified by IPCC climate regions and soil types. Soil organic C stocks (SOC) are estimated for the beginning and end of the inventory time period using default reference carbon stocks (SOC_{ref}) and default stock change factors (F_{LU}, F_{MG}, F_I).

Tier 2

For Tier 2, the same basic equations are used as in Tier 1 (Equation 2.25), but country-specific information is incorporated to specify better the stock change factors, reference C stocks, climate regions, soil types, and/or the land management classification system.

Tier 3

Tier 3 approaches may use dynamic models and/or detailed soil C inventory measurements as the basis for estimating annual stock changes. Estimates from models are computed using coupled equations that estimate the net change of soil C. A variety of models exist (e.g., see reviews by McGill *et al.,* 1996; and Smith *et al.,* 1997). Key criteria in selecting an appropriate model include its capability of representing all of the relevant management practices/systems for croplands; model inputs (i.e., driving variables) are compatible with the availability of country-wide input data; and verification against experimental data.

A Tier 3 approach may also be developed using a measurement-based approach in which a monitoring network is sampled periodically to estimate soil organic C stock changes. A much higher density of benchmark sites will likely be needed than with models to represent adequately the combination of land-use and management systems, climate, and soil types. Additional guidance is provided in Section 2.3.3.1 of Chapter 2.

Organic soils

Tier 1

Equation 2.26 (Chapter 2) is used to estimate C stock change in organic soils (e.g., peat-derived, Histosols). The basic methodology is to stratify cultivated organic soils by climate region and assign a climate-specific annual C loss rate. Land areas are multiplied by the emission factor and then summed up to estimate annual C emissions.

Tier 2

For Tier 2, the same basic equations are used as in Tier 1 (Equation 2.26), but country-specific information is incorporated to better specify emission factors, climate regions, and/or a land management classification system.

Tier 3

Tier 3 approaches for organic soils use dynamic models and/or measurement networks, as described above for mineral soils.

5.2.3.2 CHOICE OF STOCK CHANGE AND EMISSION FACTORS

Mineral soils

Tier 1

Table 5.5 provides Tier 1 approach default stock change factors for land use (F_{LU}), input (F_I) and management (F_{MG}). The method and studies that were used to derive the default stock change factors are provided in Annex 5A.1 and References. The default time period for stock changes (D) is 20 years and management practice is assumed to influence stocks to a depth of 30 cm, which is also the depth for the reference soil C stocks in Table 2.3 (Chapter 2).

Tier 2

A Tier 2 approach entails the estimation of country-specific stock change factors. Derivation of input (F_I) and management factors (F_{MG}) are based on comparisons to medium input and intensive tillage, respectively, because they are considered the nominal practices in the IPCC default management classification (see Choice of Activity Data). It is *good practice* to derive values for a higher resolution classification of management, climate and soil types if there are significant differences in the stock change factors among more disaggregated categories based on an empirical analysis. Reference C stocks can also be derived from country-specific data in a Tier 2 approach. Additional guidance is provided in Chapter 2, Section 2.3.3.1.

Tier 3

Constant stock change rate factors *per se* are less likely to be estimated in favor of variable rates that more accurately capture land-use and management effects. See Chapter 2, Section 2.3.3.1 for further discussion.

Organic soils

Tier 1

Default emission factors are provided in Table 5.6 for cultivated organic soils. Assignment of emission factors for perennial tree systems, such as fruit trees that are classified as Cropland, may be based on the factors for cultivated organic soils in Table 5.6 or forest management of organic soils (see Chapter 4). Shallower drainage will lead to emissions more similar to forest management, while deeper drainage of perennial tree systems will generate emissions more similar to annual cropping systems.

Tier 2

Emission factors are derived from country-specific experimental data in a Tier 2 approach. It is *good practice* for emission factors to be derived for specific land management categories of Cropland on organic soils and/or a finer classification of climate regions, assuming the new categories capture significant differences in C loss rates. Additional guidance is given in Chapter 2, Section 2.3.3.1.

Tier 3

Constant emission rate factors *per se* are less likely to be estimated in favor of variable rates that more accurately capture land-use and management effects.

TABLE 5.5
RELATIVE STOCK CHANGE FACTORS (F_{LU}, F_{MG}, AND F_I) (OVER 20 YEARS) FOR DIFFERENT MANAGEMENT ACTIVITIES ON CROPLAND

Factor value type	Level	Temperature regime	Moisture regime[1]	IPCC defaults	Error[2,3]	Description
Land use (F_{LU})	Long-term cultivated	Temperate/ Boreal	Dry	0.80	± 9%	Represents area that has been continuously managed for >20 yrs, to predominantly annual crops. Input and tillage factors are also applied to estimate carbon stock changes. Land-use factor was estimated relative to use of full tillage and nominal ('medium") carbon input levels.
			Moist	0.69	± 12%	
		Tropical	Dry	0.58	± 61%	
			Moist/ Wet	0.48	± 46%	
		Tropical montane[4]	n/a	0.64	± 50%	
Land use (F_{LU})	Paddy rice	All	Dry and Moist/ Wet	1.10	± 50%	Long-term (> 20 year) annual cropping of wetlands (paddy rice). Can include double-cropping with non-flooded crops. For paddy rice, tillage and input factors are not used.
Land use (F_{LU})	Perennial/ Tree Crop	All	Dry and Moist/ Wet	1.00	± 50%	Long-term perennial tree crops such as fruit and nut trees, coffee and cacao.
Land use (F_{LU})	Set aside (< 20 yrs)	Temperate/ Boreal and Tropical	Dry	0.93	± 11%	Represents temporary set aside of annually cropland (e.g., conservation reserves) or other idle cropland that has been revegetated with perennial grasses.
			Moist/ Wet	0.82	± 17%	
		Tropical montane[4]	n/a	0.88	± 50%	
Tillage (F_{MG})	Full	All	Dry and Moist/ Wet	1.00	NA	Substantial soil disturbance with full inversion and/or frequent (within year) tillage operations. At planting time, little (e.g., <30%) of the surface is covered by residues.
Tillage (F_{MG})	Reduced	Temperate/ Boreal	Dry	1.02	± 6%	Primary and/or secondary tillage but with reduced soil disturbance (usually shallow and without full soil inversion). Normally leaves surface with >30% coverage by residues at planting.
			Moist	1.08	± 5%	
		Tropical	Dry	1.09	± 9%	
			Moist/ Wet	1.15	± 8%	
		Tropical montane[4]	n/a	1.09	± 50%	
Tillage (F_{MG})	No-till	Temperate/ Boreal	Dry	1.10	± 5%	Direct seeding without primary tillage, with only minimal soil disturbance in the seeding zone. Herbicides are typically used for weed control.
			Moist	1.15	± 4%	
		Tropical	Dry	1.17	± 8%	
			Moist/ Wet	1.22	± 7%	
		Tropical montane[4]	n/a	1.16	± 50%	

TABLE 5.5 (CONTINUED)
RELATIVE STOCK CHANGE FACTORS (F_{LU}, F_{MG}, AND F_I) (OVER 20 YEARS) FOR DIFFERENT MANAGEMENT ACTIVITIES ON CROPLAND

Factor value type	Level	Temper-ature regime	Moist-ure regime[1]	IPCC defaults	Error[2,3]	Description
Input (F_I)	Low	Tem-perate/ Boreal	Dry	0.95	± 13%	Low residue return occurs when there is due to removal of residues (via collection or burning), frequent bare-fallowing, production of crops yielding low residues (e.g., vegetables, tobacco, cotton), no mineral fertilization or N-fixing crops.
			Moist	0.92	± 14%	
		Tropical	Dry	0.95	± 13%	
			Moist/ Wet	0.92	± 14%	
		Tropical montane[4]	n/a	0.94	± 50%	
Input (F_I)	Med-ium	All	Dry and Moist/ Wet	1.00	NA	Representative for annual cropping with cereals where all crop residues are returned to the field. If residues are removed then supplemental organic matter (e.g., manure) is added. Also requires mineral fertilization or N-fixing crop in rotation.
Input (F_I)	High with-out manure	Tem-perate/ Boreal and Tropical	Dry	1.04	± 13%	Represents significantly greater crop residue inputs over medium C input cropping systems due to additional practices, such as production of high residue yielding crops, use of green manures, cover crops, improved vegetated fallows, irrigation, frequent use of perennial grasses in annual crop rotations, but without manure applied (see row below).
			Moist/ Wet	1.11	± 10%	
		Tropical montane[4]	n/a	1.08	± 50%	
Input (F_I)	High – with manure	Tem-perate/ Boreal and Tropical	Dry	1.37	± 12%	Represents significantly higher C input over medium C input cropping systems due to an additional practice of regular addition of animal manure.
			Moist/ Wet	1.44	± 13%	
		Tropical montane[4]	n/a	1.41	± 50%	

[1] Where data were sufficient, separate values were determined for temperate and tropical temperature regimes; and dry, moist, and wet moisture regimes. Temperate and tropical zones correspond to those defined in Chapter 3; wet moisture regime corresponds to the combined moist and wet zones in the tropics and moist zone in temperate regions.

[2] ± two standard deviations, expressed as a percent of the mean; where sufficient studies were not available for a statistical analysis to derive a default, uncertainty was assumed to be ± 50% based on expert opinion. NA denotes 'Not Applicable', where factor values constitute defined reference values, and the uncertainties are reflected in the reference C stocks and stock change factors for land use.

[3] This error range does not include potential systematic error due to small sample sizes that may not be representative of the true impact for all regions of the world.

[4] There were not enough studies to estimate stock change factors for mineral soils in the tropical montane climate region. As an approximation, the average stock change between the temperate and tropical regions was used to approximate the stock change for the tropical montane climate.

Note: See Annex 5A.1 for the estimation of default stock change factors for mineral soil C emissions/removals for Cropland.

TABLE 5.6 **ANNUAL EMISSION FACTORS (EF) FOR CULTIVATED ORGANIC SOILS**		
Climatic temperature regime[1]	**IPCC default (tonnes C ha^{-1} yr^{-1})**	**Error** [2]
Boreal/Cool Temperate	5.0	± 90%
Warm Temperate	10.0	± 90%
Tropical/Sub-Tropical	20.0	± 90%

[1] Climate classification is provided in Chapter 3.

[2] Represents a nominal estimate of error, equivalent to two times standard deviation, as a percentage of the mean. Estimates are based on Glenn *et al*., 1993; Kasimir-Klemedtsson *et al*., 1997; Freibauer and Kaltschmitt, 2001; Leifeld *et al*., 2005; Augustin *et al*., 1996; Nykänen *et al*., 1995; Maljanen *et al*., 2001, 2004; Lohila *et al*., 2004; Ogle *et al*., 2003; Armentano and Menges, 1986.

5.2.3.3 CHOICE OF ACTIVITY DATA

Mineral soils

Tier 1

Cropland systems are classified by practices that influence soil C storage. The default management classification system is provided in Figure 5.1. Inventory compilers should use this classification to categorize management systems in a manner consistent with the default Tier 1 stock change factors. This classification may be further developed for Tiers 2 and 3 approaches. In general, practices that are known to increase C storage, such as irrigation, mineral fertilization, organic amendments, cover crops and high residue yielding crops, have higher inputs, while practices that decrease C storage, such as residue burning/removal, bare fallow, and low residue crop varieties, have lower inputs. These practices are used to categorize management systems and then estimate the change in soil organic C stocks. Practices should not be considered that are used in less than 1/3 of a given cropping sequence (i.e., crop rotation), which is consistent with the classification of experimental data used to estimate the default stock change factors. Rice production, perennial croplands, and set-aside lands (i.e., lands removed from production) are considered unique management systems (see below).

Each of the annual cropping systems (low input, medium input, high input, and high input w/organic amendment) are further subdivided based on tillage management. Tillage practices are divided into no-till (direct seeding without primary tillage and only minimal soil disturbance in the seeding zone; herbicides are typically used for weed control), reduced tillage (primary and/or secondary tillage but with reduced soil disturbance that is usually shallow and without full soil inversion; normally leaves surface with >30% coverage by residues at planting) and full tillage (substantial soil disturbance with full inversion and/or frequent, within year tillage operations, while leaving <30% of the surface covered by residues at the time of planting). It is *good practice* only to consider reduced and no-till if they are used continuously (every year) because even an occasional pass with a full tillage implement will significantly reduce the soil organic C storage expected under the reduced or no-till regimes (Pierce *et al*., 1994; Smith *et al*., 1998). Assessing the impact of rotational tillage systems (i.e., mixing reduced, no-till and/or full tillage practices) on soil C stocks will require a Tier 2 method.

The main types of land-use activity data are: i) aggregate statistics (Approach 1), ii) data with explicit information on land-use conversions but without specific geo-referencing (Approach 2), or iii) data with explicit information on land-use conversions and geo-referencing (Approach 3), such as land-use and management inventories making up a statistically-based sample of a country's land area (see Chapter 3 for discussion of approaches). At a minimum, globally available land-use and crop production statistics, such as FAO databases (http://faostat.fao.org/), provide annual compilations of total land area by major land-uses, select management data (e.g., irrigated vs. non-irrigated cropland), land area in 'perennial' crops (i.e., vineyards, perennial herbaceous crops, and tree-based crops such as orchards) and annual crops (e.g., wheat, rice, maize, sorghum, etc.). FAO databases would be an example of aggregate data (Approach 1).

Management activity data supplement the land-use data, providing information to classify management systems, such as crop types and rotations, tillage practices, irrigation, manure application, residue management, etc. These data can also be aggregate statistics (Approach 1) or information on explicit management changes (Approach 2 or 3). Where possible, it is *good practice* to determine the specific management practices for land areas associated with cropping systems (e.g., rotations and tillage practice), rather than only area by crop. Remote sensing data are a valuable resource for land-use and management activity data, and potentially, expert knowledge is another source of information for cropping practices. It is *good practice* to elicit expert knowledge using methods provided in Volume 1, Chapter 2 (eliciting expert knowledge).

National land-use and resource inventories, based on repeated surveys of the same locations, constitute activity data gathered using Approach 2 or 3, and have some advantages over aggregated land-use and cropland management data (Approach 1). Time series data can be more readily associated with a particular cropping system (i.e., combination of crop type and management over a series of years), and the soil type can be determined by sampling or by referencing the location to a suitable soil map. Inventory points that are selected based on an appropriate statistical design also enable estimates of the variability associated with activity data, which can be used as part of a formal uncertainty analysis. An example of a survey using Approach 3 is the National Resource Inventory in the U.S. (Nusser and Goebel, 1997).

Activity data require additional in-country information to stratify areas by climate and soil types. If such information has not already been compiled, an initial approach would be to overlay available land cover/land-use maps (of national origin or from global datasets such as IGBP_DIS) with soil and climate maps of national origin or global sources, such as the FAO Soils Map of the World and climate data from the United Nations Environmental Program. A detailed description of the default climate and soil classification schemes is provided in Chapter 3, Annex 3A.5. The soil classification is based on soil taxonomic description and textural data, while climate regions are based on mean annual temperatures and precipitation, elevation, occurrence of frost, and potential evapotranspiration.

Tier 2

Tier 2 approaches are likely to involve a more detailed stratification of management systems than in Tier 1 (see Figure 5.1) if sufficient data are available. This can include further subdivisions of annual cropping input categories (i.e., low, medium, high, and high with amendment), rice cultivation, perennial cropping systems, and set-asides. It is *good practice* to further subdivide default classes based on empirical data that demonstrates significant differences in soil organic C storage among the proposed categories. In addition, Tier 2 approaches can involve a finer stratification of climate regions and soil types.

Tier 3

For application of dynamic models and/or a direct measurement-based inventory in Tier 3, similar or more detailed data on the combinations of climate, soil, topographic and management data are needed, relative to the Tiers 1 and 2 methods, but the exact requirements will depend on the model or measurement design.

Organic soils

Tier 1

In contrast to the mineral soil method, croplands on organic soils are not classified into management systems under the assumption that drainage associated with all types of management for crops stimulates oxidation of organic matter previously built up under a largely anoxic environment. However, in order to apply the method described in Section 2.3.3.1 (Chapter 2), croplands do need to be stratified by climate region and soil type (see Chapter 3, Annex 3A.5 for guidance on soil and climate classifications).

Similar databases and approaches as those outlined for *Mineral Soils* in the Tier 1 discussion can be used for deriving area estimates. The land area with organic soils that are managed for Cropland can be determined using an overlay of a land-use map on climate and soils maps. Country-specific data on drainage projects combined with land-use surveys can be used to obtain a more refined estimate of the relevant areas.

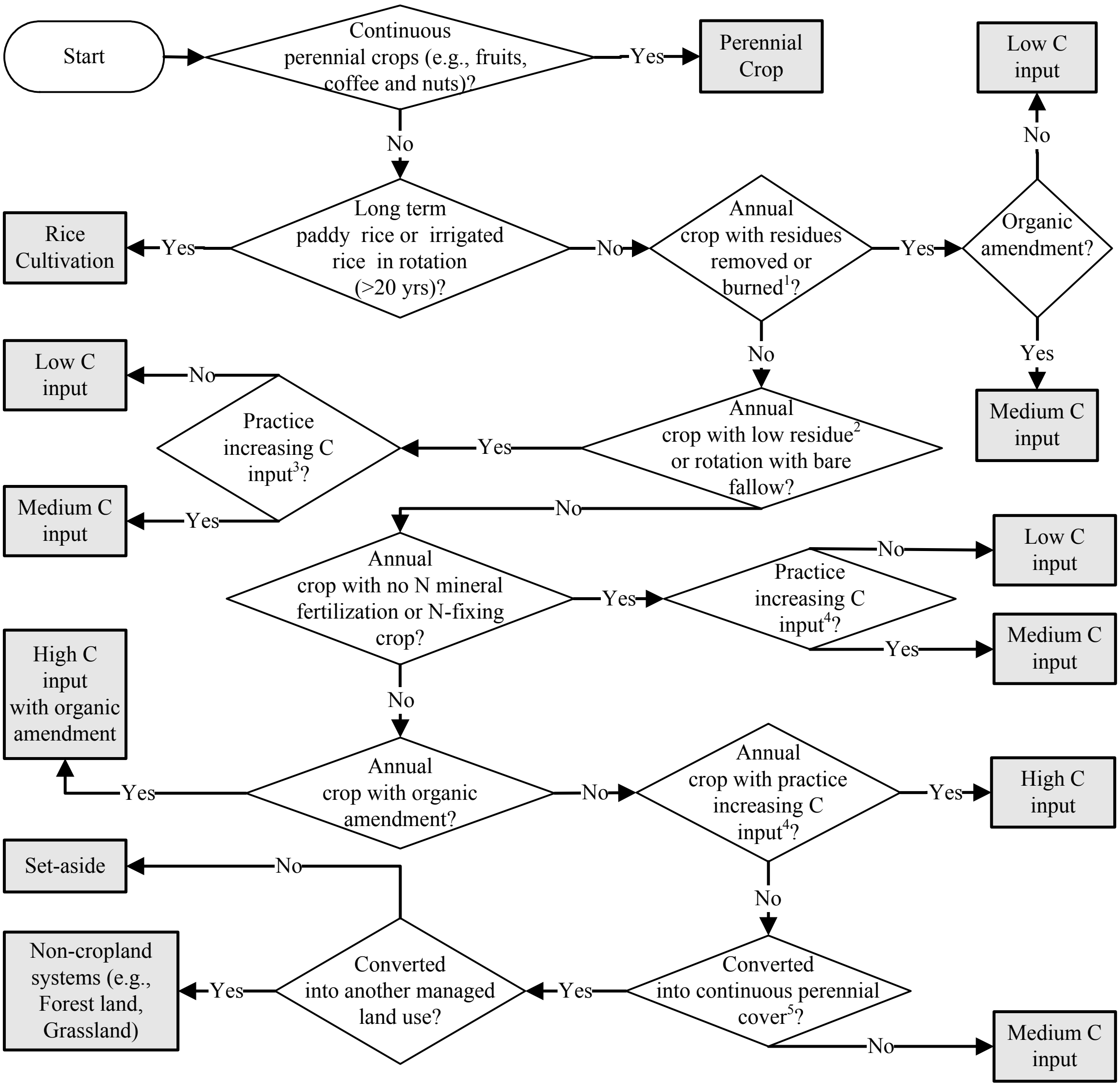
Tier 2

Tier 2 approaches may involve a stratification of management systems if sufficient data are available. This can include subdivisions of annual cropping systems by drainage class, crop type (Freibauer, 2003) or tillage disturbance. In addition, Tier 2 approaches can involve a finer stratification of climate regions.

Tier 3

Tier 3 approaches for organic soils are likely to include more detailed data on climate, soil, topographic and management data, relative to the Tiers 1 and 2 methods, but the exact requirements will depend on the model or measurement design.

Figure 5.1 Classification scheme for cropland systems. In order to classify cropland management systems, the inventory compiler should start at the top and proceed through the diagram answering questions (move across branches if answer is yes) until reaching a terminal point on the diagram. The classification diagram is consistent with default stock change factors in Table 5.5. C input classes (i.e., low, medium, high and high with organic amendment) are further subdivided by tillage practice.



Note:
1: Does not typically include grazing of residues in the field.
2: e.g. cotton, vegetables and tobacco.
3: Practices that increase C input above the amount typically generated by the low residues yielding varieties such as using organic amendments, cover crops/green manures, and mixed crop/grass systems.
4: Practices that increase C input by enhancing residue production, such as using irrigation, cover crops/green manures, vegetated fallows, high residue yielding crops, and mixed crop/grass systems.
5 Perennial cover without frequent harvest.
Note: Only consider practices, such as irrigation, residue burning/removal, mineral fertilizers, N-fixing crops, organic amendment, cover crops/green manures, low residue crop, or fallow, if used in at least 1/3 of cropping rotation sequence.

5.2.3.4 CALCULATION STEPS FOR TIER 1

Mineral soils

The steps for estimating SOC_0 and $SOC_{(0-T)}$ and net soil C stock change per ha for *Cropland Remaining Cropland* on mineral soils are as follows:

Step 1: Organize data into inventory time periods based on the years in which activity data were collected (e.g., 1990 to 1995, 1995 to 2000, etc.)

Step 2: Determine the amount *Cropland Remaining Cropland* by mineral soil types and climate regions in the country at the beginning of the first inventory time period. The first year of the inventory time period will depend on the time step of the activity data (0-T; e.g., 5, 10 or 20 years ago).

Step 3: Classify each Cropland into the appropriate management system using Figure 5.1.

Step 4: Assign a native reference C stock values (SOC_{REF}) from Table 2.3 based on climate and soil type.

Step 5: Assign a land-use factor (F_{LU}), management factor (F_{MG}) and C input levels (F_I) to each Cropland based on the management classification (Step 2). Values for F_{LU}, F_{MG} and F_I are given in Table 5.5.

Step 6: Multiply the factors (F_{LU}, F_{MG}, F_I) by the reference soil C stock (SOC_{REF}) to estimate an 'initial' soil organic C stock ($SOC_{(0-T)}$) for the inventory time period.

Step 7: Estimate the final soil organic C stock (SOC_0) by repeating Steps 1 to 5 using the same native reference C stock (SOC_{REF}), but with land-use, management and input factors that represent conditions for each cropland in the last (year 0) inventory year.

Step 8: Estimate the average annual change in soil organic C stocks for *Cropland Remaining Cropland* ($\Delta C_{Mineral}$) by subtracting the 'initial' soil organic C stock ($SOC_{(0-T)}$) from the final soil organic C stock (SOC_0), and then dividing by the time dependence of the stock change factors (i.e., 20 years using the default factors). If an inventory time period is greater than 20 years, then divide by the difference in the initial and final year of the time period.

Step 9: Repeat steps 2 to 8 if there are additional inventory time periods (e.g., 1990 to 2000, 2001 to 2010, etc.).

A numerical example is given below for *Cropland Remaining Cropland* on mineral soils, using Equation 2.25 and default reference C stocks (Table 2.3) and stock change factors (Table 5.5).

Example: The following example shows calculations for aggregate areas of cropland soil carbon stock change. In a warm temperate wet climate on Mollisol soils, there are 1Mha of permanent annual cropland. The native reference carbon stock (SOC_{REF}) for the region is 88 tonnes C ha^{-1}. At the beginning of the inventory calculation period (in this example, 10 yrs earlier in 1990), the distribution of cropland systems were 400,000 ha of annual cropland with low carbon input levels and full tillage and 600,000 ha of annual cropland with medium input levels and full tillage. Thus, initial soil carbon stocks for the area were: 400,000 ha ● (88 tonnes C ha^{-1} ● 0.69 ● 1 ● 0.92) + 600,000 ha ● (88 tonnes C ha^{-1} ● 0.69 ● 1 ● 1) = 58.78 million tonnes C. In the last year of the inventory time period (in this example, the last year is 2000), there are: 200,000 ha of annual cropping with full tillage and low C input, 700,000 ha of annual cropping with reduced tillage and medium C input, and 100,000 ha of annual cropping with no-till and medium C input. Thus, total soil carbon stocks in the inventory year are: 200,000 ha ● (88 tonnes C ha^{-1} ● 0.69 ● 1 ● 0.92) + 700,000 ha ● (88 tonnes C ha^{-1} ● 0.69 ● 1.08 ● 1) + 100,000 ha ● (88 tonnes C ha^{-1} ● 0.69 ● 1.15 ● 1) = 64.06 million tonnes C. Thus, the average annual stock change over the period for the entire area is: 64.06 – 58.78 = 5.28 million tonnes/20 yr = 264,000 tonnes C per year soil C stock increase (Note: 20 years is the time dependence of the stock change factor, i.e., factor represents annual rate of change over 20 years).

Organic soils

The steps for estimating the loss of soil C from drained organic soils are as follows:

Step 1: Organize data into inventory time periods based on the years in which activity data were collected (e.g., 1990 to 1995, 1995 to 2000, etc.)

Step 2: Determine the amount of *Cropland Remaining Cropland* on organic soils for the last year of each inventory time period.

Step 3: Assign the appropriate emission factor (EF) for annual losses of CO_2 based on climate (from Table 5.6).

Step 4: Estimate total emissions by summing the product of area (A) multiplied by the emission factor (EF) for all climate zones.

Step 5: Repeat for additional inventory time periods.

A numerical example is given below for *Cropland Remaining Cropland* on drained organic soils, using Equation 2.26 and default emission factors (Table 5.6).

Example: The following example shows calculations for aggregate areas of cropland soil carbon stock change. In a warm temperate wet climate on Histosols, there are 0.4 Mha of permanent annual cropland on drained organic soils. The emission factor for this climate is 10.0 tonnes C ha^{-1} yr^{-1}. Thus, annual soil carbon stock change for organic soils during the inventory time period is: 400,000 ha ● 10.0 tonnes C ha^{-1} = 4.0 million tonnes C yr^{-1}.

5.2.3.5 UNCERTAINTY ASSESSMENT

Three broad sources of uncertainty exist in soil C inventories: 1) uncertainties in land-use and management activity, and environmental data; 2) uncertainties in reference soil C stocks if using a Tier 1 or 2 approach (mineral soils only); and 3) uncertainties in the stock change/emission factors for Tier 1 or 2 approaches, model structure/parameter error for Tier 3 model-based approaches, or measurement error/sampling variability associated with Tier 3 measurement-based inventories. In general, precision of an inventory is increased and confidence ranges are smaller with more sampling to estimate values for the three board categories, while reducing bias (i.e., improve accuracy) is more likely to occur through the development of a higher Tier inventory that incorporates country-specific information.

For Tier 1, uncertainties are provided with the reference C stocks in the first footnote in Table 2.3, stock change factors in Table 5.5, and emission factor for organic soils in Table 5.6. Uncertainties in land-use and management data will need to be addressed by the inventory compiler, and then combined with uncertainties for the default factors and reference C stocks (mineral soils only) using an appropriate method, such as simple error propagation equations. If using aggregate land-use area statistics for activity data (e.g., FAO data), the inventory agency may have to apply a default level of uncertainty for the land area estimates (±50%). It is *good practice* for the inventory compiler to derive uncertainties from country-specific activity data instead of using a default level.

Default reference C stocks and stock change factors for mineral soils and emission factors for organic soils can have inherently high uncertainties, particularly bias, when applied to specific countries. Defaults represent globally averaged values of land-use and management impacts or reference C stocks that may vary from region-specific values (Powers *et al*., 2004; Ogle *et al*., 2006). Bias can be reduced by deriving country-specific factors using a Tier 2 method or by developing a Tier 3 country-specific estimation system. The underlying basis for higher Tier approaches will be experiments in the country or neighbouring regions that address the effect of land use and management on soil C. In addition, it is *good practice* to further minimize bias by accounting for significant within-country differences in land-use and management impacts, such as variation among climate regions and/or soil types, even at the expense of reduced precision in the factor estimates (Ogle *et al*., 2006). Bias is considered more problematic for reporting stock changes because it is not necessarily captured in the uncertainty range (i.e., the true stock change may be outside of the reported uncertainty range if there is significant bias in the factors).

Uncertainties in land-use activity statistics may be reduced through a better national system, such as developing or extending a ground-based survey with additional sample locations and/or incorporating remote sensing to provide additional coverage. It is *good practice* to design a classification that captures the majority of land-use and management activity with a sufficient sample size to minimize uncertainty at the national scale.

For Tier 2 methods, country-specific information is incorporated into the inventory analysis for purposes of reducing bias. For example, Ogle *et al.* (2003) utilized country-specific data to construct probability distribution functions for US specific factors, activity data and reference C stocks for agricultural soils. It is *good practice* to evaluate dependencies among the factors, reference C stocks or land-use and management activity data. In particular, strong dependencies are common in land-use and management activity data because management practices tend to be correlated in time and space. Combining uncertainties in stock change/emission factors, reference C stocks and activity data can be done using methods such as simple error propagation equations or Monte-Carlo procedures to estimate means and standard deviations for the change in soil C stocks (Ogle *et al*., 2003; Vanden Bygaart *et al*., 2004).

Tier 3 models are more complex and simple error propagation equations may not be effective at quantifying the associated uncertainty in resulting estimates. Monte Carlo analyses are possible (Smith and Heath, 2001), but can be difficult to implement if the model has many parameters (some models can have several hundred parameters) because joint probability distribution functions must be constructed quantifying the variance as well as covariance among the parameters. Other methods are also available such as empirically-based approaches (Monte *et al*., 1996), which use measurements from a monitoring network to statistically evaluate the relationship between measured and modelled results (Falloon and Smith, 2003). In contrast to modelling, uncertainties in measurement-based Tier 3 inventories can be estimated from the sample variance, measurement error and other relevant sources of uncertainty.

5.2.4 Non-CO_2 greenhouse gas emissions from biomass burning

Non-CO_2 emissions from *Cropland Remaining Cropland* (particularly CH_4, CO, NO_x and N_2O) are usually associated with burning of agriculture residues, which vary by country, crop, and management system. CO_2 emissions from biomass burning do not have to be reported, since the carbon released during the combustion process is assumed to be reabsorbed by the vegetation during the next growing season.

The percentage of the agricultural crop residues burnt on-site, which is the mass of fuel available for burning, should be estimated taking into account the fractions removed before burning due to animal consumption, decay in the field, and use in other sectors (e.g., biofuel, domestic livestock feed, building materials, etc.). This is important to eliminate the possibility of double counting.

The methodology for estimating non-CO_2 emissions from biomass burning in *Cropland Remaining Cropland* follows the generic formulation in Equation 2.27 in Chapter 2. The estimates should be based on annual data.

5.2.4.1 CHOICE OF METHOD

The decision tree in Figure 2.6 in Chapter 2 provides general guidance on the choice of the appropriate Tier to be used. The method of estimation of greenhouse gas emission from biomass burning involves the use of Equation 2.27 (Chapter 2). Under a Tier 1 approach, the activity data are normally highly aggregated, and combustion and emissions factors are the default values provided in Chapter 2. Under a Tier 2, estimates are generally developed for the major crop types by climate zone, using country-specific residue accumulation rates and country-specific combustion and emission estimates. Tier 3 is a very country-specific method involving process modelling and/or detailed measurement.

All countries should strive for improving inventory and reporting approaches by applying the highest Tier possible, given national circumstances. If burning in *Cropland Remaining Cropland* is a key category, countries should use either Tier 2 or Tier 3 method.

5.2.4.2 CHOICE OF EMISSION FACTORS

Tier 1

Countries applying a Tier 1 method should replace quantities M_B and C_f in Equation 2.27 in Chapter 2 by the appropriate default fuel consumption value (M_B x C_f) in Table 2.4. The default emission factors to be used are provided in Table 2.5 for each greenhouse gas of interest.

Tier 2

This method expands Tier 1 to include use of country-specific available fuel, combustion and emission factors. Countries may estimate the amount of available fuel from crop production statistics and from the ratio of crop yield and residue produced. Field studies are needed to estimate the fractions of crop residue removed from field (as fuel or fodder) and left as residue for burning for different crop systems. Countries should focus on the most dominant crops being burnt or the systems with relatively high biomass per hectare and levels of emissions per unit of land (e.g., sugarcane, cotton).

Tier 3

This tier makes use of models based on country-specific parameters, using national inventory data to ensure that no burning of crop residues is omitted. Tier 3 depends on the field measurement of the amount of residues burnt on-site for different cropping systems under different climate zones and management systems, based on sampling methods described in Chapter 3 (Annex 3A.3). Countries should prioritize the development of country-specific combustion and emission factors, by focusing on the most dominant crop residues being burnt.

5.2.4.3 CHOICE OF ACTIVITY DATA

Tier 1

Activity data includes estimates of land areas under the crop types for which agricultural residues are normally burnt. This can be obtained in consultation with national agricultural governmental sectors, in the lack of objective data from satellite imagery, for example. Countries can also estimate the crop area planted from the annual crop production and an estimate of the average productivity per hectare. If no national estimates are available, FAO statistics can be used. It is *good practice* to cross check FAO data with national sources.

Tier 2

Under a Tier 2 method, countries should use more disaggregated area estimates (e.g., major crop types by climate zone) with country-specific and crop management system-specific residue accumulation rates. This can be accomplished through the use of more detailed annual or periodic surveys to estimate the areas of land under different crop classes. Areas should be further classified into relevant categories such that all major combinations of crop types and climatic regions are represented, with individual area estimates provided.

Tier 3

Tier 3 requires high-resolution activity data disaggregated at sub-national to fine grid scales. Similar to Tier 2, land area is classified into specific types of crops by major climate and soil categories and other potentially important regional variables (e.g., regional patterns of management practices) to be used in models. Countries should strive to obtain spatially explicit area estimates to facilitate complete coverage of the cropland and ensure that areas are not over- nor under-estimated. Additionally, spatially explicit area estimates can be related to locally relevant emission rates and management impacts, improving the accuracy of the estimates. Area data for different cropping systems used should be consistent with area used in earlier sections (Biomass, Dead organic matter), though residues may be burnt on only a part of the total area.

5.2.4.4 UNCERTAINTY ASSESSMENT

Estimates of the area planted under each crop type for which residues are normally burnt may be highly uncertain. Global statistics of crop production, which may be an indirect way to estimate area planted, if not updated on a yearly basis, may be very uncertain. The fraction of the agricultural residue that is burnt in the field is possibly the variable with most uncertainty. Tier 2 estimates are more precise, being based on country-specific parameters. It is *good practice* to provide error estimates (i.e., standard deviation, standard error, ranges) for country-specific combustion and emission factors and areas burnt.

5.3 LAND CONVERTED TO CROPLAND

Globally, about 50% of the total land surface has been transformed by direct human action, 20% of land ecosystems have been converted to permanent croplands, and 25% of the world's forests have been cleared for various uses such as crop cultivation and pastures (Moore, 2002). Area under cropland has been increasing in some parts of the world to meet growing food and fibre demands. Most of the expansion of cropland in the last two decades has occurred in Southeast Asia, parts of South Asia, the Great Lakes region of eastern Africa and the Amazon Basin (Millennium Ecosystems Assessment, 2005). During the same period, forest destruction in the tropics averaged 12 million hectares per year according to Environmental Group Limited (http://www.environmental.com.au/). Deforestation rate during the 1990's averaged 14.6 million ha per year. Conversion to Cropland is a leading land-use change following tropical deforestation. Greenhouse gas emissions and removals from *Land Converted to Cropland* can be a key source for many countries.

Estimation of annual greenhouse gas emissions and removals from *Land Converted to Cropland* includes the following:

- Estimates of annual change in C stocks from all C pools and sources:
    - Biomass (above-ground and below-ground biomass);
    - Dead organic matter (dead wood and litter);
    - Soils (soil organic matter).

- Estimates of non-CO_2 gases (CH_4, CO, N_2O, NO_x) from burning of above-ground biomass and DOM

5.3.1 Biomass

5.3.1.1 CHOICE OF METHODS

This section provides guidance on methods for calculating carbon stock change in biomass due to the conversion of land from natural conditions and other uses to Cropland, including deforestation and conversion of pasture and grazing lands to Cropland. The methods require estimates of carbon in biomass stocks prior to and following conversion, based on estimates of the areas of lands converted during the period between land-use surveys. As a result of conversion to Cropland, it is assumed (in Tier 1) that the dominant vegetation is removed entirely leading to emissions, resulting in near zero amounts of carbon remaining in biomass. Some type of cropping system is planted soon thereafter increasing the amount of carbon stored in biomass. The difference between initial and final biomass carbon pools is used to calculate carbon stock change from land-use conversion; and in subsequent years accumulations and losses in perennial woody biomass in Cropland are counted using methods in Section 5.2.1 (*Cropland Remaining Cropland*).

It is *good practice* to consider all carbon pools (i.e., above ground and below ground biomass, dead organic matter, and soils) in estimating changes in carbon stocks in *Land Converted to Cropland*. Currently, there is insufficient information to provide a default approach with default parameters to estimate carbon stock change in dead organic matter (DOM) pools[2]. DOM is unlikely to be important except in the year of conversion. It is assumed that there will be no DOM in Cropland. In addition, the methodology below considers only carbon stock change in above-ground biomass since limited data are available on below-ground carbon stocks in perennial Cropland.

The *IPCC Guidelines* describe increasingly sophisticated alternatives that incorporate greater detail on the areas of land converted, carbon stocks on lands, and loss of carbon resulting from land conversions. It is g*ood practice* to adopt the appropriate tier depending on key source analysis, data availability and national circumstances. All countries should strive for improving inventory and reporting approaches by advancing to the highest tier possible given national circumstances. It is *good practice* for countries to use a Tier 2 or Tier 3 approach if carbon emissions and removals in *Land Converted to Cropland* is a key category and if the sub-category of biomass is considered significant based on principles outlined in Volume 1, Chapter 4. Countries should use the decision tree in Figure 1.3 to help with the choice of method. *Land Converted to Cropland* is likely to be a key category for many countries and further biomass is likely to be a key source.

Tier 1

The Tier 1 method follows the approach in Chapter 4 (Forest Land) where the amount of biomass that is cleared for cropland is estimated by multiplying the area converted in one year by the average carbon stock in biomass in the Forest Land or Grassland prior to conversion. It is *good practice* to account completely for all land conversions to Cropland. Thus, this section elaborates on the method such that it includes different initial uses, including but not limited to forests.

Equation 2.15 in Chapter 2 summarises the major elements of a first-order estimation of carbon stock change from land-use conversion to Cropland. Average carbon stock change on a per hectare basis is estimated for each type of conversion. The average carbon stock change is equal to the carbon stock change due to the removal of biomass from the initial land use (i.e., carbon in biomass immediately after conversion minus the carbon in biomass prior to conversion), plus carbon stocks from one year of growth in Cropland following conversion. It is necessary to account only for any woody vegetation that replaces the vegetation that was cleared during land-use conversion. The *GPG-LULUCF* combines carbon in biomass after conversion and carbon in biomass that grows on the land following conversion into a single term. In this method, they are separated into two terms, B_{AFTER} and ΔC_G to increase transparency.

At Tier 1, carbon stocks in biomass immediately after conversion (B_{AFTER}) are assumed to be zero, since the land is cleared of all vegetation before planting crops. Average carbon stock change per hectare for a given land-use conversion is multiplied by the estimated area of lands undergoing such a conversion in a given year. In subsequent years, change in biomass of annual crops is considered zero because carbon gains in biomass from annual growth are offset by losses from harvesting. Changes in biomass of perennial woody crops are counted following the methodology in Section 2.3.1.1 (Change in carbon stocks in biomass in land remaining in a land-use category).

[2] Any litter and dead wood pools (estimated using the methods described in Chapter 2, Section 2.3.2) should be assumed oxidized following land conversion.

The default assumption for Tier 1 is that all carbon in biomass removed is lost to the atmosphere through burning or decay processes either on-site or off-site. Tier 1 calculations do not differentiate immediate emissions from burning and other conversion related losses.

Tier 2

The Tier 2 calculations are structurally similar to Tier 1, with the following distinctions. First, Tier 2 relies largely on country-specific estimates of the carbon stocks in initial and final land uses rather than the default data. Area estimates for *Land Converted to Cropland* are disaggregated according to original vegetation (e.g., from Forest Land or Grassland) at finer spatial scales to capture regional and crop systems variations in country-specific carbon stocks values.

Second, Tier 2 may modify the assumption that carbon stocks immediately following conversion are zero. This enables countries to take into account land-use transitions where some, but not all, vegetation from the original land use is removed.

Third, under Tier 2, it is *good practice* to apportion carbon losses to burning and decay processes if applicable. Emissions of carbon dioxide occur as a result of burning and decay in land-use conversions. Further, non-CO_2 trace gas emissions occur as a result of burning. By partitioning losses to burning and decay, countries can also calculate non-CO_2 trace gas emissions from burning (Section 5.3.4).

The immediate impacts of land conversion activities on the five carbon stocks can be summarized in a disturbance matrix, which describes the retention, transfers and releases of carbon in the pools in the original ecosystem following conversion to Cropland. A disturbance matrix defines for each pool the proportion that remains in that pool and the proportion that is transferred to other pools. A small number of transfers are possible, and are outlined in a disturbance matrix in Table 5.7. The disturbance matrix ensures consistency of the accounting of all carbon pools.

Biomass transfers to dead wood and litter can be estimated using Equation 2.20.

Tier 3

The Tier 3 method is similar to Tier 2, with the following distinctions: i) rather than relying on average annual rates of conversion, countries can use direct estimates of spatially disaggregated areas converted annually for each initial and final land use; ii) carbon densities and soil carbon stock change are based on locally specific information, which makes possible a dynamic link between biomass and soil; and iii) biomass volumes are based on actual inventories. The transfer of biomass, to dead wood and litter following land-use conversion can be estimated using Equation 2.20.

TABLE 5.7
EXAMPLE OF A SIMPLE DISTURBANCE MATRIX (TIER 2) FOR THE IMPACTS OF LAND CONVERSION ACTIVITIES ON CARBON POOLS

To / From	Above-ground biomass	Below-ground biomass	Dead wood	Litter	Soil organic matter	Harvested wood products	Atmosphere	Sum of row (must equal 1)
Above-ground biomass								
Below-ground biomass								
Dead wood								
Litter								
Soil organic matter								

Enter the proportion of each pool on the left side of the matrix that is transferred to the pool at the top of each column. All of the pools on the left side of the matrix must be fully accounted, so the values in each row must sum to 1.

Impossible transitions are blacked out.

5.3.1.2 CHOICE OF EMISSION/REMOVAL FACTORS

The emission/removal factors needed for the default method are: carbon stocks before conversion in the initial land use and after conversion to Cropland; and growth in biomass carbon stock from one year of cropland growth.

Tier 1

Default biomass carbon stock in initial land-use categories (B_{BEFORE}) mainly Forest Land and Grassland are provided in Table 5.8. Initial land-use based carbon stocks should be obtained for different Forest Land or Grassland categories based on biome type, climate, soil management systems, etc. It is assumed that all biomass is cleared when preparing a site for cropland use, thus, the default for B_{AFTER} is 0 tonne C ha^{-1}.

In addition, a value is needed for carbon stocks after one year of growth in crops planted after conversion (ΔC_G). Table 5.9 provides defaults for ΔC_G. Separate defaults are provided for annual non-woody crops and perennial woody crops. For lands planted in annual crops, the default value of ΔC_G is 5 tonnes of C per hectare, based on the original *IPCC Guidelines* recommendation of 10 tonnes of dry biomass per hectare (dry biomass has been converted to tonnes carbon in Table 5.9). The total accumulation of carbon in perennial woody biomass will, over time, exceed that of the default carbon stock for annual cropland. However, default values provided in this section are for one year of growth immediately following conversion, which usually give lower carbon stocks for perennial woody crops compared to annual crops.

TABLE 5.8
DEFAULT BIOMASS CARBON STOCKS REMOVED DUE TO LAND CONVERSION TO CROPLAND

Land-use category	Carbon stock in biomass before conversion (B_{Before}) (tonnes C ha^{-1})	Error range #
Forest Land	See Chapter 4 Tables 4.7 to 4.12 for carbon stocks in a range of forest types by climate regions. Stocks are in terms of dry matter. *Multiply values by a carbon fraction (CF) 0.5 to convert dry matter to carbon.*	See Section 4.3 (Land Converted to Forest Land)
Grassland	See Chapter 6 for carbon stocks in a range of grassland types by climate regions.	± 75%

Represents a nominal estimate of error, equivalent to two times standard deviation, as a percentage of the mean.

TABLE 5.9
DEFAULT BIOMASS CARBON STOCKS PRESENT ON LAND CONVERTED TO CROPLAND IN THE YEAR FOLLOWING CONVERSION

Crop type by climate region	Carbon stock in biomass after one year (ΔC_G) (tonnes C ha^{-1})	Error range#
Annual cropland	5.0	± 75%
Perennial cropland		
Temperate (all moisture regimes)	2.1	± 75%
Tropical, dry	1.8	± 75%
Tropical, moist	2.6	± 75%
Tropical, wet	10.0	± 75%

Represents a nominal estimate of error, equivalent to two times standard deviation, as a percentage of the mean.

Tier 2

Tier 2 methods should include some country-specific estimates for biomass stocks and removals due to land conversion, and also include estimates of on-site and off-site losses due to burning and decay following land conversion to Cropland. These improvements can take the form of systematic studies of carbon content and emissions and removals associated with land uses and land-use conversions within the country and a re-examination of default assumptions in light of country-specific conditions.

Default parameters for emissions from burning and decay are provided. However, countries are encouraged to develop country-specific coefficients to improve the accuracy of estimates. The *IPCC Guidelines* use a general default of 0.5 for the proportion of biomass burnt on-site for both Forest Land and Grassland conversions. Research studies suggest that the fraction is highly variable and could be as low as 0.2 (Fearnside, 2000; Barbosa and Fearnside, 1996; and Fearnside, 1990). Updated default proportions of biomass burnt on-site are provided in Chapter 4 (Forest Land) for a range of forest vegetation classes. These defaults should be used for transitions from Forest Land to Cropland. For non-forest initial land uses, the default proportion of biomass left on-site and burnt is 0.35. This default takes into consideration research, which suggests the fraction should fall within the range 0.2 to 0.5 (e.g., Fearnside, 2000; Barbosa and Fearnside, 1996; and Fearnside, 1990). It is *good practice* for countries to use 0.35 or another value within this range, provided that the rationale for the choice is documented. There is no default value for the amount of biomass taken off-site and burnt; countries will need to develop a proportion based on national data sources. In Chapter 4 (Forest Land), the default proportion of biomass oxidized as a result of burning is 0.9, as originally stated in the *GPG-LULUCF*.

The method for estimating emissions from decay assumes that all biomass decays over a period of 10 years. For reporting purposes countries have two options: 1) report all emissions from decay in one year, recognizing that in reality they occur over a 10 year period, and 2) report all emission from decay on an annual basis, estimating the rate as one tenth of the totals. If countries choose the latter option, they should add a multiplication factor of 0.10 to the equation.

Tier 3
Under Tier 3, all parameters should be country-defined using measurements and monitoring for more accurate values rather than the defaults. Process based models and decay functions can also be used.

5.3.1.3 CHOICE OF ACTIVITY DATA

All tiers require estimates of land areas converted to Cropland. The same area estimates should be used for both biomass and soil C calculations on *Land Converted to Cropland*. Higher tiers require greater specificity of areas. At a minimum, the area of Forest Land and natural Grassland converted to Cropland should be identified separately for all tiers. This implies at least some knowledge of the land uses prior to conversion. This may also require expert judgment if Approach 1 in Chapter 3 of these guidelines is used for land area identification.

Tier 1
Separate estimates are required of areas converted to Cropland from initial land uses (i.e., Forest Land, Grassland, Settlements, etc.) to final crop land type (i.e., annual or perennial) (A_{TO_OTHERS}). For example, countries should estimate separately the area of tropical moist forest converted to annual cropland, tropical moist forest converted to perennial cropland, tropical moist Grassland converted to perennial cropland, etc. Although, to allow other pools to equilibrate and for consistency with land area estimation overall, land areas should remain in the conversion category for 20 years (or other period reflecting national circumstances) following conversion. The methodology assumes that area estimates are based on a one-year time frame, which is likely to require estimation on the basis of average rates on land-use conversion, determined by measurements estimates made at longer intervals. If countries do not have these data, partial samples may be extrapolated to the entire land base or historic estimates of conversions may be extrapolated over time based on the judgement of country experts. Under Tier 1 calculations, international statistics such as FAO databases, *IPCC GPG Reports* and other sources, supplemented with sound assumptions, can be used to estimate the area of *Land Converted to Cropland* from each initial land use. For higher tier calculations, country-specific data sources are used to estimate all possible transitions from initial land use to final crop type.

Tier 2
It is *good practice* for countries to use actual area estimates for all possible transitions from initial land use to final crop type. Full coverage of land areas can be accomplished either through analysis of periodic remotely sensed images of land-use and land cover patterns, through periodic ground-based sampling of land-use patterns, or hybrid inventory systems. If finer resolution country-specific data are partially available, countries are encouraged to use sound assumptions from best available knowledge to extrapolate to the entire land base. Historic estimates of conversions may be extrapolated over time based on the judgment of country experts.

Tier 3
Activity data used in Tier 3 calculations should be a full accounting of all land-use transitions to Cropland and be disaggregated to account for different conditions within a country. Disaggregation can occur along political (county, province, etc.), biome, climate, or on a combination of such parameters. In many cases, countries may have information on multi-year trends in land conversion (from periodic sample-based or remotely sensed inventories of land use and land cover). Periodic land-use change matrix need to be developed giving the initial and final land-use areas at disaggregated level based on remote sensing and field surveys.

5.3.1.4 CALCULATION STEPS FOR TIERS 1 AND 2

The following summarizes steps for estimating change in carbon stocks in biomass (ΔC_B) using the default methods

Using the worksheet provided for *Land Converted to Cropland* (see Annex 1, AFOLU Worksheets), calculate the change in biomass carbon stocks in *Land Converted to Cropland* as follows:

Step 1: Enter the subcategories of croplands for the reporting year. The subcategories of croplands used in Section 5.2 may also be used to fill out the appropriate column in the worksheet.

Step 2: For each sub-category, enter the annual area of land converted to Cropland (A_{TO_OTHERS}). Data for annual area may be obtained from various sources such as the Ministry of Forestry, Ministry of Agriculture, Ministry of Planning, or Mapping Office within a country.

Step 3: For each sub-category, enter the carbon stocks in biomass immediately after conversion to Cropland (B_{AFTER}), in tonnes C ha^{-1}. Biomass and carbon data may be default values or country-specific values.

Step 4: For each sub-category, enter the carbon stocks in biomass immediately before conversion to Cropland (B_{BEFORE}), in tonnes C ha^{-1}. Biomass and carbon data may be default values or country-specific values.

Step 5: Calculate the carbon stocks change per area ($C_{CONVERSION}$) for the type of conversion when land is converted to Cropland (Equation 2.16).

Step 6: Obtain the values for change in carbon stocks from one year of cropland growth (ΔC_G) and the decrease in biomass carbon due to losses ((ΔC_L) using Table 5.1. Enter the values in the appropriate column.

Step 7: Calculate the annual change in carbon stocks in biomass in *Land Converted to Cropland* (ΔC_B) using Equation 2.15.

Step 8: Sum up all the annual changes in carbon stocks in biomass.

5.3.1.5 UNCERTAINTY ASSESSMENT

Tier 1

The sources of uncertainty in this method are from the use of global or national average rates of conversion and from estimates of land areas converted to Cropland. In addition, reliance on default parameters for carbon stocks in initial and final conditions contributes to relatively high degrees of uncertainty. The default values in this method have error ranges associated with them. A published compilation of research on carbon stocks in agroforestry systems was used to derive the default data provided in Section 5.2 (Schroeder, 1994). While defaults were derived from multiple studies, their associated uncertainty ranges were not included in the publication. Therefore, a default uncertainty level of $\pm$75% of the carbon stock has been assumed based on expert judgement. *Land Converted to Cropland* is likely to be a key source category for many countries and all efforts should be made to reduce uncertainty.

Tier 2

The Tier 2 method uses at least some country-defined defaults, which will improve the accuracy of estimates, because they better represent conditions relevant to the country. Use of country-specific values should entail sufficient sample sizes and or use of expert judgment to estimate uncertainties. This, together with uncertainty estimates on activity data derived using the advice in Chapter 3, should be used in the approaches to uncertainty analysis as described in Volume 1, Chapter 3 of this report.

Tier 3

Activity data from a land-use and management inventory system should provide a basis to assign estimates of uncertainty to areas associated with land-use changes. Combining emission and activity data and their associated uncertainties can be done using Monte-Carlo procedures to estimate means and confidence intervals for the overall inventory. The uncertainty is likely to be less than for other tiers since estimates of carbon stock changes are based on more measurements and more refined models.

5.3.2 Dead organic matter

Forest Land, Grassland, Settlements, and other land-use categories could be potentially converted to Cropland which, in general will have little or no dead wood or litter, with the exception of agroforestry systems. Methods are provided for two types of dead organic matter pools: 1) dead wood, and 2) litter. Chapter 1of this report provides detailed definitions of these pools.

Dead wood is a diverse pool which is difficult to measure, with associated uncertainties about rates of transfer to litter, soil, or emissions to the atmosphere.

Litter accumulation depends on litterfall, which includes all leaves, twigs and small branches, fruits, flowers, and bark, minus the rate of decomposition. The litter mass is also influenced by the time since the last disturbance, and the type of disturbance. During the early stages of cropland development, litter increases rapidly. Management such as vegetation harvesting and burning dramatically alter litter stocks, but there are very few studies clearly documenting the effects of management on litter carbon.

In general, croplands will have little or no dead wood or litter, and therefore these pools can often be assumed to approach zero after conversion, the exception being agroforestry systems which may be accounted either under Cropland or Forest Land, depending upon definitions adopted by countries for reporting. It is likely that the same will be true of many land uses prior to conversion, so that corresponding carbon pools prior to conversion can also be assumed to be zero. The exceptions are forest, agro-forests, and wetlands converted to Cropland, which could have significant carbon in DOM pools, as well as forest areas around settlements that may have been defined as Settlements based on nearby use rather than land cover.

Estimating change in carbon stocks in DOM for lands converted to Cropland under higher tiers requires a two-phase approach. During the first phase, there is often an abrupt change in DOM associated with the land-use change, particularly then the change is deliberate and associated with land preparation operations (e.g., clearing and burning). The second phase accounts for decay and accumulation processes during a transition period to a new steady-state system. At some point in time, the cropland ecosystem should reach an equilibrium at which time it can be considered *Cropland Remaining Cropland* and accounted for under that category. The transition period should be 20 years, but some countries can determine the appropriate transition period more accurately at higher tiers.

To account for the transition period, lands converted to Cropland should be treated as annual cohorts. That is, land converted in a given year should be accounted for with Phase 1 methods in the year of conversion, and with Phase 2 methods for the subsequent 19 years. At the end of the 20 year period, the land area for that given year is added to the land area being accounted under the *Cropland Remaining Cropland* category.

5.3.2.1 CHOICE OF METHOD

The decision tree in Figure 2.3 in Chapter 2 provides assistance in the selection of the appropriate tier level for the implementation of estimation procedures. Estimation of changes in carbon stocks in DOM requires an estimate of changes in stocks of dead wood and changes in litter stocks (refer to Equation 2.17 in Chapter 2).

Each of the DOM pools (dead wood and litter) is to be treated separately, but the method for each pool is the same.

Tier 1

A Tier 1 approach involves estimating the area of each type of land conversion using only the major conversion categories (e.g., Forest Land to Cropland). The immediate and abrupt carbon stock change (Phase 1) in dead wood and litter due to conversion of other lands to Cropland under Tier 1 will be estimated using Equation 2.23 in Chapter 2. C_0 in Equation 2.23 is likely to be zero and there is no need to divide T_{on}. The Tier 1 default assumes removal of all dead wood and litter during conversion and that there is no dead wood or litter that remains or accumulates in *Land Converted to Cropland*. Countries where this assumption is known to be false (e.g., where slash and burn agriculture is widely practiced) are encouraged to use a higher tier when accounting for lands converted to Cropland. Additionally, it is assumed that croplands achieve their steady-state biomass during the first year following conversion. Thus, for Tier 1, Phase 2 has no transition period and lands converted to Cropland are transferred to *Cropland Remaining Cropland* in the second year following conversion.

There are no default values available for dead wood or litter in most systems. For forests, there are no global default values for dead wood, but there are values for litter (Table 2.2 in Chapter 2). These values are in terms of tonnes C ha^{-1}, not in terms of litter stocks. Countries should make best estimates and use local data from forestry and agricultural research institutes to provide best estimates of the dead wood and litter in the initial system prior to conversion.

Tier 2

Tier 2 approaches require greater disaggregation than that used in Tier 1. Activity data should be reported by management regimes. Tier 2 also employs the two-phase approach described above.

As recommended above in the biomass section, the immediate impacts of land conversion activities on the five carbon stocks can be summarized in a disturbance matrix. The disturbance matrix describes the retention, transfers and releases of carbon in the pools in the original ecosystem following conversion to Cropland. A disturbance matrix defines the proportion of the carbon stock that remains in that pool and the proportion that is transferred to other pools. A small number of transfers are possible, and are outlined in the disturbance matrix in Table 5.7. Use of a disturbance matrix ensures consistency of the accounting of all carbon pools.

The immediate and abrupt carbon stock change in dead wood due to conversion of other lands to Cropland under Tiers 2 and 3 will be estimated using Equation 2.23 in Chapter 2 as suggested in Tier 1. During the transition period, pools that gain or lose carbon often have a non-linear loss or accumulation curve that can be represented through successive transition matrices. For Tier 2, a linear change function can be assumed; a Tier 3 approach based upon this method should use the true shapes of the curves. These curves should be applied to each cohort that is under transition during the reporting year to estimate the annual change in the dead wood and litter carbon pools.

For the calculation of changes in dead wood and litter carbon during the transition phase, two methods are suggested:

Method 1 (Also called the **Gain-Loss Method,** Equation 2.18 in Chapter 2): Method 1 involves estimating the area of each type of land conversion and the average annual transfer into and out of dead wood and litter stocks. This requires an estimate of area under *Land Converted to Cropland* according to different climate or cropland types, management regime, or other factors significantly affecting dead wood and litter carbon pools and the quantity of biomass transferred into dead wood and litter stocks as well as the quantity of biomass transferred out of the dead wood and litter stocks on per hectare basis according to different cropland types.

Method 2 (Also called the **Stock-Difference Method,** Equation 2.19 in Chapter 2): Method 2 involves estimating the area of *Land Converted to Cropland* and then estimating dead wood and litter stocks at two periods of time, t_1 and t_2. The dead wood and litter stock changes for the inventory year are obtained by dividing the stock changes by the period (years) between two measurements. The stock difference method is feasible for countries, which have periodic inventories. This method is more suitable for countries adopting Tier 3 methods. Tier 3 methods are used where countries have country-specific emission factors, and substantial national data. Country-defined methodology may be based on detailed inventories of permanent sample plots for their croplands and/or models.

Tier 3

For Tier 3, countries should develop their own methodologies and parameters for estimating changes in DOM. These methodologies may be derived from both methods specified above, or may be based on other approaches. The method used needs to be clearly documented.

Method 2 may be suitable for countries adopting Tier 3 methods. Tier 3 methods are used where countries have country-specific emission factors, and substantial national data. Country-defined methodology may be based on detailed inventories of permanent sample plots for their grasslands and/or models.

5.3.2.2 CHOICE OF EMISSION/REMOVAL FACTORS

Carbon Fraction: The carbon fraction of dead wood and litter is variable and depends on the stage of decomposition. Wood is much less variable than litter and a value of 0.50 tonne C (tonne d.m.)$^{-1}$ can be used for the carbon fraction.

Tier 1

For Tier 1, it is assumed that the dead wood and litter carbon stocks in lands converted to Cropland are all lost during the conversion and that there is no accumulation of new DOM in the Cropland after conversion. Countries experiencing significant conversions of other ecosystems to Cropland that have a significant component of dead wood or litter (e.g., slash and burn systems for clearing land, agroforestry, etc.) are encouraged to develop domestic data to quantify this impact and report it under Tier 2 or 3 methodologies.

Tier 2

It is *good practice* to use country-level data on dead wood and litter for different Cropland categories, in combination with default values, if country or regional values are not available for some conversion categories. Country-specific values for transfer of carbon from live trees and other crops that are harvested to harvest residues and decomposition rates, in the case of Method 1 (Gain-Loss Method), or the net change in DOM pools, in the case of Method 2 (Stock-Difference Method), can be derived from domestic expansion factors, taking into account the Cropland type, the rate of biomass utilization, harvesting practices and the amount of damaged vegetation during harvesting operations. Country-specific values for disturbance regimes should be derived from scientific studies.

Tier 3

National level disaggregated DOM carbon estimates should be determined as part of a national land-use inventory, national level models, or from a dedicated greenhouse gas inventory programme, with periodic sampling according to the principles set our in Chapter 3 Annex 3A.3. Inventory data can be coupled with modelling studies to capture the dynamics of all Cropland carbon pools.

Tier 3 methods provide estimates of greater certainty than lower tiers and feature a greater link between individual carbon pools. Some countries have developed disturbance matrices that provide a carbon reallocation pattern among different pools for each type of disturbance. Other important parameters in a modelled DOM carbon budget are decay rates, which may vary with the type of wood and microclimatic conditions, and site preparation procedures (e.g., controlled broadcast burning, or burning of piles).

5.3.2.3 CHOICE OF ACTIVITY DATA

Activity data should be consistent with the activity data used for estimating changes in biomass on land areas converted to Cropland. This can be obtained, consistent with the general principles set out in Chapter 3 and as described earlier through national statistics, from forest services, conservation agencies, municipalities, survey and mapping agencies. Cross-checks should be made to ensure complete and consistent representation of annually converted lands in order to avoid possible omissions or double counting. Data should be disaggregated according to the general climatic categories and Cropland types. Tier 3 inventories will require more comprehensive information on the establishment of new croplands, with refined soil classes, climates, and spatial and temporal resolution. All changes having occurred over the number of years selected as the transition period should be included with transitions older than the transition period (default 20 years) reported as a subdivision of *Cropland Remaining Cropland*.

All tiers require estimates of land areas converted to Cropland. The same area data should be used for biomass calculations, dead organic matter and the soil carbon estimates. If necessary, area data used in the soils analysis can be aggregated to match the spatial scale required for lower order estimates of biomass; however, at higher tiers, stratification should take account of major soil types. Area data should be obtained using the methods described in Chapter 3. Higher tiers require greater detail but the minimum requirement for inventories to be consistent with the *IPCC Guidelines* is that the areas of forest conversion can be identified separately. This is because forest will usually have higher carbon density before conversion. This implies that at least partial knowledge of the land-use change matrix, and therefore, where Approaches 1 and 2 from Chapter 3 are used to estimate land area are being used, supplementary surveys may be needed to identify the area of land being converted from Forest Land to Cropland. As pointed out in Chapter 3, where surveys are being set up, it will often be more accurate to determine directly areas undergoing conversion, than to estimate these from the differences in total land areas under particular uses at different times.

5.3.2.4 CALCULATION STEPS FOR TIERS 1 AND 2

Tier 1

Step 1: Determine the categories of land conversion to be used in this assessment and the representative area of conversion by year (A_{on}). Area data should be obtained using the methods described in Chapter 3. Higher tiers require greater detail but the minimum requirement for inventories to be consistent with the *IPCC Guidelines* when using Tier 1 is that the areas of Forest Land conversion to Cropland can be identified separately.

Step 2: For each activity category, determine the dead wood and litter stocks (separately) per hectare prior to conversion (ΔC_o).

Step 3: For each activity category, determine the stocks in the dead wood and litter (separately) per hectare for the particular type of cropland after conversion (ΔC_n). For Tier 1, dead wood and litter stocks following conversion are assumed to be equal to zero.

Step 4: Calculate the net change of dead wood and litter stocks per hectare for each type of conversion by subtracting the initial stocks from the final stocks. A negative value indicates a loss in the stock.

Step 5: Convert the net change in the individual stock to units of tonnes C ha^{-1} by multiplying the net stock change by the carbon fraction of that stock (0.40 tonne C $(\text{tonne d.m.})^{-1}$ for litter, and 0.50 tonne C $(\text{tonne d.m.})^{-1}$ for dead wood).

Step 6: Multiply the net change in each C stock by the area converted during the reporting year, to get the annual change in carbon stocks in dead wood and litter (ΔC_{DOM}).

Tier 2

Step 1: Determine the categories of land conversion to be used in this assessment and the representative area of conversion by year. When calculating for lands in the transition phase, representative areas for each category at different stages of conversion are required.

Step 2: Abrupt changes

- Determine the activity categories to be used in this assessment and the representative areas. The category consists of definitions of the type of conversion and, if applicable, the nature of management of the previous land cover and cropland management, for example: 'conversion of logged tropical seasonal forest to cereal crops'.
- For each activity category, determine the dead wood and litter stocks (separately) per hectare prior to conversion.
- For each activity category, determine the stocks in the dead wood and litter (separately) per hectare following one year of conversion to Cropland.
- Calculate the net change of dead wood and litter stocks per hectare for each type of conversion by subtracting the initial stocks from the final stocks. A negative value indicates a loss in the stock.
- Convert the net change in the individual stock to units of tonnes C ha^{-1} as mentioned in Tier 1.
- Multiply the net change in each C stock by the area converted during the reporting year.

Step 3: Transitional changes

- Determine the activity categories and cohorts to be used in this assessment and the representative areas. The category consists of definitions of the type of conversion and, if applicable, the nature of management of the previous land cover and cropland management, for example: 'conversion of logged tropical seasonal forest to cattle pasture using exotic grasses'.
- Determine the annual change rate for dead wood and litter stocks (separately) by activity type using either Method 1 (Gain-Loss Method) or Method 2 (Stock-Difference Method) (see below) for each cohort of lands that are currently in the transition phase between conversion and a new steady-state cropland system.
- Determine the dead wood and litter stocks in the cohort during the previous year (usually taken from the previous inventory).
- Calculate the change in dead wood and litter stocks for each cohort by adding the net change rate to the previous year's stocks.
- Convert the net change in the individual stock to units of tonnes C ha^{-1} as described in Tier 1.
- Multiply the net change in each C stock by the area in each cohort for the reporting year.

Method 1 (Gain-Loss Method; see Equation 2.18 in Chapter 2)

- Determine the average annual inputs of dead wood and litter (separately).
- Determine the average annual losses of dead wood and litter (separately).
- Determine the net change rate in dead wood and litter by subtracting the outputs from the inputs.
- A Tier 2 approach requires country-specific and cropping system-specific stock change factors and the best available local data should be used (and documented).

Method 2 (Stock-Difference Method; see Equation 2. 19 in Chapter 2)

- Determine the inventory time interval, the average stocks of dead wood and litter at the initial inventory, and the average stocks of dead wood and litter at the final inventory.
- Use these figures to calculate the net change in dead wood and litter stocks by subtracting the initial stock from the final stock and dividing this difference by the number of years between inventories. A negative value indicates a loss in the stock.
- A Tier 2 approach requires country-specific and cropping system-specific stock change factors and the best available local data should be used (and documented).

5.3.2.5 UNCERTAINTY ASSESSMENT

This section considers source-specific uncertainties relevant to estimates made for lands converted to Cropland. Sources of uncertainty include the degree of accuracy in land area estimates, carbon increase and loss, carbon stock, fraction of land area burnt, and expansion factor terms. Error estimates (i.e., standard deviations, standard error, or ranges) must be calculated for each of the country-defined terms used in a basic uncertainty assessment.

Emission factor uncertainties

These will be the same as the uncertainties associated with estimation of the litter and dead organic matter stocks per unit area on the previous land use. Uncertainties need not be estimated where zero carbon density in litter and dead organic matter pools is assumed for Cropland. Where this is not the case, uncertainties should be assessed by analysis of local data and should both exceed a factor of about 2.

Activity data uncertainties

Area data and estimates of uncertainty should be obtained using the methods in Chapter 3. Tiers 2 and 3 approaches may also use higher resolution activity data, such as area estimates for different climatic regions or for cropland management systems within national boundaries. This will reduce uncertainty levels when associated with carbon accumulation factors defined at the same resolution.

5.3.3 Soil carbon

Land is typically converted to Cropland from native lands, managed Forest Land and Grassland, but occasionally conversions can occur from Wetlands and seldom Settlements. Regardless of soil type (i.e., mineral or organic), the conversion of land to Cropland will, in most cases, result in a loss of soil C for some years following conversion (Mann, 1986; Armentano and Menges, 1986; Davidson and Ackerman, 1993). Possible exceptions are irrigation of formerly arid lands and conversion of degraded lands to Cropland.

General information and guidance for estimating changes in soil C stocks are provided in Section 2.3.3 of Chapter 2 (including equations), and that section needs to be read before proceeding with a consideration of specific guidelines dealing with cropland soil C stocks. The total change in soil C stocks for *Land Converted to Cropland* is estimated using Equation 2.24 (Chapter 2), which combines the change in soil organic C stocks (SOC stocks) for mineral soils and organic soils; and stock changes associated with soil inorganic C pools (Tier 3 only). This section provides specific guidance for estimating soil organic C stock changes; see Section 2.3.3.1 for discussion on soil inorganic C (no additional guidance is provided in the Cropland section below).

To account for changes in soil C stocks associated with *Land Converted to Cropland*, countries need to have, at a minimum, estimates of the areas of *Land Converted to Cropland* during the inventory time period. If land-use and management data are limited, aggregate data, such as FAO statistics, can be used as a starting point, along with knowledge of country experts of the approximate distribution of land-use types being converted and their associated management. If the previous land uses and conversions are not unknown, SOC stocks changes can still be computed using the methods provided in *Cropland Remaining Cropland*, but the land base area will likely be different for croplands in the current year relative to the initial year in the inventory. It is critical, however, that the total land area across all land-use sectors be equal over the inventory time period (e.g., 7 million ha may be converted from Forest Land and Grassland to Cropland during the inventory time period, meaning that croplands will have an additional 7 Million ha in the last year of the inventory, while grasslands and forests will have a corresponding loss of 7 Million ha in the last year). *Land Converted to Cropland* is stratified according to climate regions and major soil types, which could either be based on default or country-specific classifications. This can be accomplished with overlays of climate and soil maps, coupled with spatially-explicit data on the location of land conversions.

5.3.3.1 CHOICE OF METHOD

Inventories can be developed using a Tier 1, 2 or 3 approach with each successive tier requiring more detail and resources than the previous one. It is also possible that countries will use different tiers to prepare estimates for the separate subcategories of soil C (i.e., soil organic C stocks changes in mineral soils and organic soils; and stock changes associated with soil inorganic C pools). Decision trees are provided for mineral soils (Figure 2.4) and organic soils (Figure 2.5) in Section 2.3.3.1 (Chapter 2) to assist inventory compilers with selection of the appropriate tier for their soil C inventory.

Mineral soils

Tier 1

Soil organic C stock changes for mineral soils can be estimated for land-use conversion to Cropland using Equation 2.25 in Chapter 2. For Tier 1, the initial (pre-conversion) soil organic C stock ($SOC_{(0-T)}$) and C stock in the last year of the inventory time period (SOC_0) are computed from the default reference soil organic C stocks (SOC_{REF}) and default stock change factors (F_{LU}, F_{MG}, F_I). Annual rates of stock changes are estimated as the difference in stocks (over time) divided by the time dependence (D) of the Cropland stock change factors (default is 20 years).

Tier 2

The Tier 2 method for mineral soils also uses Equation 2.25 in Chapter 2, but incorporates country-specific reference C stocks and/or stock change factors, and possibly more disaggregated land-use activity and environmental data.

Tier 3

Tier 3 methods will involve more detailed and country-specific models and/or measurement-based approaches along with highly disaggregated land-use and management data. Tier 3 approaches estimate soil C change from land-use conversions to Cropland, and may employ models, data sets and/or monitoring networks. If possible, it is recommended that Tier 3 methods be integrated with estimates of biomass removal and the post-clearance treatment of plant residues (including woody debris and litter), as variation in the removal and treatment of residues (e.g., burning, site preparation) will affect C inputs to soil organic matter formation and C losses through decomposition and combustion. It is important that models be evaluated with independent observations from country-specific or region-specific field locations that are representative of the interactions of climate, soil and cropland management on post-conversion change in soil C stocks.

Organic soils

Tier 1 and Tier 2

Land Converted to Cropland on organic soils within the inventory time period is treated the same as long-term cropped organic soils. Carbon losses are computed using Equation 2.26 (Chapter 2). Additional guidance on the Tiers 1 and 2 approaches are given in the *Cropland Remaining Cropland* section (Section 5.2.3).

Tier 3

A Tier 3 approach will involve more detailed and country-specific models and/or measurement-based approaches along with highly disaggregated land-use and management data (see mineral soils above for further discussion).

5.3.3.2 CHOICE OF STOCK CHANGE AND EMISSION FACTORS

Mineral soils

Tier 1

For native unmanaged land, as well as for managed forest lands, settlements and nominally managed grasslands with low disturbance regimes, soil C stocks are assumed equal to the reference values (i.e., land-use, disturbance (forests only), management and input factors equal 1), while it will be necessary to apply the appropriate stock change factors to represent previous land-use systems that are not the reference condition, such as improved and degraded grasslands. It will also be necessary to apply the appropriate stock change factor to represent input and management effects on soil C storage in the new cropland system. Default reference C stocks are found in Table 2.3 (Chapter 2). See the appropriate land-use chapter for default stock change factors.

In the case of transient land-use conversions to Cropland, the stock change factors are given in Table 5.10, and depend on the length of the fallow (vegetation recovery) cycle in a shifting cultivation system, representing an average soil C stock over the crop-fallow cycle. Mature fallow denotes situations where the non-cropland vegetation (e.g., forests) recovers to a mature or near mature state prior to being cleared again for cropland use, whereas in shortened fallow, vegetation recovery is not attained prior to re-clearing. If land already in shifting-cultivation is converted to permanent Cropland (or other land uses), the stock change factors representing shifting cultivation would provide the 'initial' C stocks ($SOC_{(0-T)}$) in the calculations using Equation 2.25 (Chapter 2).

TABLE 5.10
SOIL STOCK CHANGE FACTORS (F_{LU}, F_{MG}, F_I) FOR LAND-USE CONVERSIONS TO CROPLAND

Factor value type	Level	Climate regime	IPCC default	Error #	Definition
Land use	Native forest or grassland (non-degraded)	All	1	NA	Represents native or long-term, non-degraded and sustainably managed forest and grasslands.
		Tropical	1	NA	
Land use	Shifting cultivation – Shortened fallow	Tropical	0.64	± 50%	Permanent shifting cultivation, where tropical forest or woodland is cleared for planting of annual crops for a short time (e.g., 3-5 yr) period and then abandoned to regrowth.
	Shifting cultivation – Mature fallow	Tropical	0.8	± 50%	
Land-use, Management, & Input	Managed forest	(default value is 1)			
Land-use, Management, & Input	Managed grassland	(See default values in Table 6.2)			
Land-use, Management, & Input	Cropland	(See default values in Table 5.5)			

Represents a nominal estimate of error, equivalent to two times standard deviation, as a percentage of the mean. NA denotes 'Not Applicable', where factor values constitute defined reference values.

Tier 2
Estimation of country-specific stock change factors is probably the most important development associated with the Tier 2 approach. Differences in soil organic C stocks among land uses are computed relative to a reference condition, using land-use factors (F_{LU}). Input factors (F_I) and management factors (F_{MG}) are then used to further refine the C stocks of the new cropland system. Additional guidance on how to derive these stock change factors is given in *Croplands Remaining Croplands*, Section 5.2.3.2. See the appropriate chapter for specific information regarding the derivation of stock change factors for other land-use categories (Forest Land in Section 4.2.3.2, Grassland in 6.2.3.2, Settlements in 8.2.3.2, and Other Land in 9.3.3.2).

Reference C stocks can also be derived from country-specific data in a Tier 2 approach. However, reference values should be consistent across the land uses (i.e., Forest Land, Cropland, Grassland, Settlements, Other Land), and thus must be coordinated among the various teams conducting soil C inventories for AFOLU.

Tier 3
Constant stock change rate factors *per se* are less likely to be estimated in favor of variable rates that more accurately capture land-use and management effects. See Chapter 2, Section 2.3.3.1 for further discussion.

Organic soils

Tier 1 and Tier 2
Land Converted to Cropland on organic soils within the inventory time period is treated the same as long-term cropped organic soils. Tier 1 emission factors are given in Table 5.6, while Tier 2 emission factors are derived from country-specific or region-specific data.

Tier 3
Constant emission rate factors *per se* are less likely to be estimated in favor of variable rates that more accurately capture land-use and management effects. See Chapter 2, Section 2.3.3.1 for further discussion.

5.3.3.3 CHOICE OF ACTIVITY DATA

Mineral soils

Tier 1 and Tier 2
For purposes of estimating soil carbon stock change, area estimates of *Land Converted to Cropland* should be stratified according to major climate regions and soil types. This can be based on overlays with suitable climate and soil maps and spatially-explicit data of the location of land conversions. Detailed descriptions of the default climate and soil classification schemes are provided in Chapter 3, Annex 3A.5. Specific information is provided

in the each of the land-use chapters regarding treatment of land-use/management activity data (Forest Land in Section 4.2.3.3, Cropland in 5.2.3.3, Grassland in 6.2.3.3, Settlements in 8.2.3.3, and Other Land in 9.3.3.3).

One critical issue in evaluating the impact of *Land Converted to Cropland* on soil organic C stocks is the type of land-use and management activity data. Activity data gathered using Approach 2 or 3 (see Chapter 3 for discussion about approaches) provide the underlying basis for determining the previous land use for *Land Converted to Cropland*. In contrast, aggregate data (Approach 1, Chapter 3) only provide the total amount of area in each land at the beginning and end of the inventory period (e.g., 1985 and 2005). Approach 1 data are not sufficient to determine specific transitions. In this case all Cropland will be reported in the *Cropland Remaining Cropland* category and in effect transitions become step changes across the landscape. This makes it particularly important to achieve coordination among all land sectors to ensure that the total land base is remaining constant over time, given that some land area will be lost and gained within individual sectors during each inventory year due to land-use change.

Tier 3

For application of dynamic models and/or a direct measurement-based inventory in Tier 3, similar or more detailed data on the combinations of climate, soil, topographic and management data are needed, relative to Tier 1 or 2 methods, but the exact requirements will be dependent on the model or measurement design.

Organic soils

Tiers 1 and 2

Land Converted to Cropland on organic soils within the inventory time period is treated the same as long-term cropped organic soils, and guidance on activity data is discussed in Section 5.2.3.3.

Tier 3

Similar to mineral soils, Tier 3 approaches will likely require more detailed data on the combinations of climate, soil, topographic and management data. Relative to Tier 1 or 2 methods, the exact requirements will be dependent on the model or measurement design.

5.3.3.4 CALCULATION STEPS FOR TIER 1

Mineral soils

The steps for estimating SOC_0 and $SOC_{(0-T)}$ and net soil C stock change per ha of *Land Converted to Cropland* on mineral soils are as follows:

Step 1: Organize data into inventory time periods based on the years in which activity data were collected (e.g., 1990 to 1995, 1995 to 2000, etc.)

Step 2: Determine the amount of *Land Converted to Cropland* by mineral soil types and climate regions in the country at the beginning of the first inventory time period. The first year of the inventory time period will depend on the time step of the activity data (0-T; e.g., 5, 10 or 20 years ago).

Step 3: For Grassland converted to Cropland, classify previous grasslands into the appropriate management system using Figure 6.1. No classification is needed for other land uses at the Tier 1 level.

Step 4: Assign native reference C stock values (SOC_{REF}) from Table 2.3 based on climate and soil type.

Step 5: Assign a land-use factor (F_{LU}), management factor (F_{MG}) and C input levels (F_I) to each grassland based on the management classification (Step 2). Values for F_{LU}, F_{MG} and F_I are given in Table 6.2 for grasslands. Values are assumed to be 1 for all other land uses.

Step 6: Multiply the factors (F_{LU}, F_{MG}, F_I) by the reference soil C stock to estimate an 'initial' soil organic C stock ($SOC_{(0-T)}$) for the inventory time period.

Step 7: Estimate the final soil organic C stock (SOC_0) by repeating Steps 1 to 5 using the same native reference C stock (SOC_{REF}), but with land-use, management and input factors that represent conditions for the cropland in the last (year 0) inventory year.

Step 8: Estimate the average annual change in soil organic C stocks for land converted to Cropland ($\Delta C_{Mineral}$) by subtracting the 'initial' soil organic C stock ($SOC_{(0-T)}$) from the final soil organic C stock (SOC_0), and then dividing by the time dependence of the stock change factors (i.e., 20 years using the default factors). Note: if an inventory time period is greater than 20 years, then divide by the difference in the initial and final year of the time period.

Step 9: Repeat Steps 2 to 8 if there are additional inventory time periods (e.g., 1990 to 2000, 2001 to 2010, etc.). Note that *Land Converted to Cropland* will retain that designation for 20 years. Therefore, inventory time periods that are less than 20 years may need to refer to the previous inventory time period to evaluate if a parcel of land is considered *Land Converted to Cropland* or *Cropland Remaining Cropland*.

A numerical example is given below for Forest Land converted to Cropland on mineral soils, using Equation 2.25 and default reference C stocks (Table 2.3) and stock change factors (Table 5.5).

> **Example**: For a forest on volcanic soil in a tropical moist environment: SOC_{Ref} = 70 tonnes C ha^{-1}. For all forest soils (and for native grasslands) default values for stock change factors (F_{LU} , F_{MG} , F_I) are all 1; thus $SOC_{(0-T)}$ is 70 tonnes C ha^{-1}. If the land is converted into annual cropland, with intensive tillage and low residue C inputs then SOC_0 = 70 tonnes C ha^{-1} ● 0.48 ● 1 ● 0.92 = 30.9 tonnes C ha^{-1}. Thus the average annual change in soil C stock for the area over the inventory time period is calculated as (30.9 tonnes C ha^{-1} – 70 tonnes C ha^{-1}) / 20 yrs = -2.0 tonnes C ha^{-1} yr^{-1}.

Organic soils

Calculation steps and example are the same as described in Section 5.2.3.4 above.

5.3.3.5 UNCERTAINTY ASSESSMENT

Uncertainty analyses for *Land Converted to Cropland* are fundamentally the same as *Cropland Remaining Cropland*. Three broad sources of uncertainty exists: 1) uncertainties in land-use and management activity and environmental data; 2) uncertainties in reference soil C stocks if using a Tier 1 or 2 approach (mineral soils only); and 3) uncertainties in the stock change/emission factors for Tier 1 or 2 approaches, model structure/parameter error for Tier 3 model-based approaches, or measurement error/sampling variability associated with a Tier 3 measurement-based inventories. See the uncertainty section in *Cropland Remaining Cropland* for additional discussion (Section 5.2.3.5).

5.3.4 Non-CO_2 greenhouse gas emissions from biomass burning

Greenhouse gas emissions from conversion of non-cropland, particularly Forest Land and Grassland to Cropland, are likely to be key source category for many countries. Greenhouse gas emissions from *Land Converted to Cropland* occur from incomplete combustion of biomass and dead organic matter (DOM) in the initial land-use category before conversion. CO_2 emissions are accounted for in the new land-use category (*Land Converted to Cropland*). The most significant non-CO_2 emissions in this section arise from conversion of Forest Land to Cropland, but it may also occur as a result of the conversion from Grassland to Cropland. It is very unlikely that Cropland originates from conversion of the other land-use categories (Settlements, Wetlands, or Other Land).

In the tropics, it is common practice to burn the forest residues successively, until most (or all) of the forest residues and DOM is cleared, and agriculture can be established. In some places, up to three or four burnings are necessary. Part of the above-ground forest biomass removed during the process of conversion of Forest Land to Cropland may be transferred to harvested wood products, and an amount may be removed from the site to be used as fuel wood (hence, burnt off-site). Whatever remains is normally burnt on-site.

Methods for estimating CO_2 emissions from fire for *Land Converted to Cropland* are described in Section 2.4 in Chapter 2.

Non-CO_2 emissions from biomass burning in unmanaged Forest Land, if followed by a land-use conversion, shall be reported, since the converted land is considered to be managed land.

The approach to be used to estimate non-CO_2 emissions from biomass burning in *Land Converted to Cropland* is essentially the same as for *Cropland Remaining Cropland.*

5.3.4.1 CHOICE OF METHOD

The decision tree in Figure 2.6 in Chapter 2 provides guidance on the choice of the Tier level to be applied by countries when reporting non-CO_2 emissions from *Land Converted to Cropland*. Countries experiencing significant scale conversion of non-cropland, particularly from Forest Land, to cropland should strive to adopt Tier 2 or 3 methods.

The choice of method is directly related to the availability of national data on the area of converted land burnt, the mass of fuel available, and combustion and emission factors. When using higher tiers, country-specific data on the mass of available fuel is used to represent the amount of biomass removed for conversion, and transferred to harvested wood product (if applicable), removed for fuel use and burnt off-site.

Countries should strive to report using a Tier 2 or Tier 3 method whenever greenhouse gas emissions from biomass burning in *Land Converted to Cropland* is a key category. If models have been developed and validated, countries should apply a Tier 3 method even in those cases where *Land Converted to Cropland* is not a key category.

5.3.4.2 CHOICE OF EMISSION FACTORS

Tier 1

The mass of fuel combusted is critical for estimating greenhouse gas emissions. Default data to support estimation of emissions under a Tier 1 approach are given in Tables 2.4 – 2.6 in Chapter 2. Countries need to judge how their vegetation types relate to the broad vegetation categories described in the default tables. For Tier 1, it should be assumed that all of the carbon in above-ground biomass and DOM in the previous land category is lost immediately after conversion. Default values for biomass prior to conversion can be found in the chapters relating to the respective land uses (e.g., default factors for Forest Land are to be found in the chapter dealing with biomass in Forest Land). For calculation of non-CO_2 emissions, estimates of the amount of fuel actually burnt (Table 2.4) should be used.

Tier 2

In a Tier 2 method, country-specific estimates of mass of fuel available should be used. Data should be disaggregated according to forest types, in the case of Forest Land converted to Cropland. Combustion and emission factors that reflect better the national conditions (climate zone, biome, burning conditions) should be developed and uncertainty ranges provided. In addition, unlike Tier 1, where it is assumed that all of the carbon in above-ground and DOM is lost immediately after conversion, in a Tier 2 method the transfers of biomass to harvested wood products and fuelwood (burnt off-site) should be estimated to provide a more reliable estimate of the mass of fuel available for combustion.

Tier 3

Under a Tier 3, all the parameters required for estimating CO_2 and non-CO_2 emissions should be developed nationally for different land types subjected to conversion to Cropland.

5.3.4.3 CHOICE OF ACTIVITY DATA

The activity data needed to estimate non-CO_2 emissions from biomass burning refers to the area affected by this activity. Countries shall stratify the area converted to Cropland by Forest Land and Grassland converted, since the amount of fuel available for burning may present large variations from one category of land use to another. The most critical conversion is from Forest Land to Cropland, due to large biomass involved per hectare. It is *good practice* to ensure the area data used for non-CO_2 estimation is consistent with that used for biomass and DOM sections.

Tier 1

Countries applying a Tier 1 method should estimate the areas converted to Cropland from initial land uses (Forest Land, Grassland, etc.). Countries using Approach 1 of Chapter 3 should strive to further stratify *Land Converted to Cropland* from different land-use categories. The conversion should be estimated on a yearly basis. Estimates can be derived by applying a rate of conversion to Cropland to the total area cropped annually. The rate can be estimated on the basis of historical knowledge, judgement of country experts, and/or from samples of converted areas and assessment of the final land use. Alternatively, estimates can be derived using data from international sources, such as FAO, to estimate the area of Forest Land and Grassland area annually converted, and using expert judgement to estimate the portion of this area converted to Cropland.

Tier 2

Countries should, where possible, use actual area estimates for all possible conversions to Cropland. Multi-temporal remotely sensed data of adequate resolution should provide better estimates of land-use conversion than the approaches used in Tier 1. The analysis may be based on full coverage of the territory or on representative sample areas selected, from which estimates of the area converted to Cropland in the entire territory can be derived.

Tier 3

The activity data in Tier 3 should be based on the Approach 3 method presented in Chapter 3, where the total annual area converted to Cropland (from Forest Land, Grassland, or other land-use category) is estimated. It is *good practice* to develop a land-use change matrix as suggested in Chapter 3, in a spatially explicit manner. The data should be disaggregated according to type of biome, climate, soils, political boundaries, or a combination of these parameters.

5.3.4.4 UNCERTAINTY ASSESSMENT

Tier 1

The sources of uncertainty arise from: (i) use of global or national average rates of conversion or coarse estimates of land areas converted to Cropland; (ii) estimate of the area converted that is burnt; (iii) mass of available fuel; and (iv) combustion and emission factors. Uncertainties associated with emission and combustion factors are provided, and those related to items (i) and (ii) can vary significantly depending on the method used in their estimation.

As a result of these uncertainties it is unlikely that the estimate of area burnt will be known to better than 20% and the emissions per unit area to within a factor of 2 using Tier 1 methods.

Tier 2

The use of area estimates produced from more reliable sources (remotely sensed data, sample approach) will improve the accuracy relative to Tier 1 and Approach 1 of Chapter 3. These sources will also provide better estimates of the areas that are converted and burnt. Taking into account the biomass transferred to harvested wood products or removed from the site as fuelwood, and the biomass left on-site to decay, will eliminate a bias (overestimation) in the estimates. Estimates of emission or combustion factors, if accompanied by error ranges (in the form of standard deviation), will allow uncertainty associated with *Land Converted to Cropland* to be assessed.

Tier 3

Uncertainty is less and is dependent on the accuracy of remote sensing and field surveys, and of the modelling approach used and associated data inputs.

5.4 COMPLETENESS, TIME SERIES, QA/QC, AND REPORTING

Material presented here supplements the general guidance on these issues that is provided in Volume 1.

5.4.1 Completeness

Tier 1

A complete Cropland inventory for Tier 1 has three elements: 1) carbon stock changes and non-CO_2 (CH_4, CO, N_2O, NO_x) emissions from biomass burning have been estimated for all *Land Converted to Cropland* and *Cropland Remaining Cropland* during the inventory time period, 2) inventory analysis addressed the impact of all management practices described in the Tier 1 methods, and 3) the analysis accounted for climatic and soil variation that impacts emissions and removals (as described for Tier 1).

The latter two elements require assignment of management systems to cropland areas and stratification by climate regions and soil types. It is *good practice* for countries to use the same area classifications for biomass and soil pools in addition to biomass burning (to the extent that classifications are needed for these source categories). This will ensure consistency and transparency, allow for efficient use of land surveys and other data collection tools, and enable the explicit linking between carbon dioxide emissions and removals in biomass and soil pools, as well as non-CO_2 emissions from biomass burning.

For biomass and soil C stock estimations, a cropland inventory should address the impact of land-use change (*Land Converted to Cropland*) and management. However, in some cases, activity data or expert knowledge may not be sufficient to estimate the effects of agroforestry, crop rotation practices, tillage practices, irrigation, manure application, residue management, *etc*. In those cases, countries may proceed with an inventory addressing land use alone, but the results will be incomplete and omission of management practices must be clearly identified in the reporting documentation for purposes of transparency. If there are omissions, it is *good practice* to collect additional activity data for future inventories, particularly if biomass or soil C is a key source category.

C stock changes may not be computed for some cropland areas if greenhouse gas emissions and removals are believed to be insignificant or constant through time, such as non-woody cropland where there are no management or land-use changes. In this case, it is *good practice* for countries to document and explain the reason for omissions.

For biomass burning, non-CO_2 greenhouse gases should be estimated for all major categories of crop residues, taking care to account for removal of residues from the field for other purposes such as energy production, and for losses of residues resulting from grazing and decomposition during the period between harvests and burning operations. Where there is conversion of Forest Land to Cropland, the emissions from the burning of DOM and cleared tree biomass should be included.

Tier 2

A complete Tier 2 inventory has similar elements as Tier 1 but incorporates country-specific data: to estimate C stock change factors, reference soil C stocks, residue estimates (fuel load), combustion and emission factors for biomass burning; and to develop climate descriptions and soil categories in addition to improve management system classifications. Moreover, it is *good practice* for a Tier 2 inventory to incorporate country-specific data for each component. Inventories are still considered complete, however, if they combine country- specific data with Tier 1 defaults.

Tier 3

In addition to the Tiers 1 and 2 considerations, completeness of Tier 3 inventories will depend on the components of the country-specific evaluation system. In practice, Tier 3 inventories are likely to fully account for emissions and removals from croplands using more, finely resolved data on climate, soils, biomass burning and management systems. It is *good practice* for inventory compilers to describe and document the elements of the country-specific system, demonstrating the completeness of the approach and data sources. If gaps are identified, it is *good practice* to gather additional data and further develop the country-specific system.

5.4.2 Developing a consistent time series

Tier 1

Consistent time series are essential for evaluating trends in emissions or removals. In order to maintain consistency, compilers should apply the same classifications and factors over the entire inventory time period, including climate, soil types, management system classifications, C stock change factors, reference soil C stocks, residue estimates (fuel load), combustion factors, and non-CO_2 emission factors. Defaults are provided for all of these characteristics and so consistency should not be an issue. In addition, the land base should also remain consistent through time, with the exception of *Land Converted to Cropland* or Cropland converted to other land uses.

Countries should use consistent sources of activity data on land use, management and biomass burning, throughout the inventory. Sampling approaches, if used, should be maintained for the duration of the inventory time period to ensure a consistent approach. If subcategories are created, countries should keep transparent records of how they are defined and apply them consistently throughout the inventory.

In some cases, sources of activity data, definitions or methods may change over time with availability of new information. Inventory compilers should determine the influence of changing data or methods on trends, and if deemed significant, emissions and removals should be re-calculated for the time series using methods provided in Chapter 5 of Volume 1.

For C stock changes, one key element in producing a consistent time series is to ensure consistency between C stocks for lands converted to Cropland that were reported in previous reporting periods and the state of those stocks reported for those lands that are remaining Cropland in the current reporting period. For example, if 50 tonnes of the above-ground live biomass was transferred to the dead organic matter pool for land converted from Forest Land to Cropland in the previous reporting period, reporting in this period must assume that the starting carbon stocks in the dead organic matter pool was 50 tonnes for those lands.

Tier 2

In addition to the issues discussed under Tier 1, there are additional considerations associated with introduction of country-specific information. Specifically, it is *good practice* to apply new values or classifications derived from country-specific information across the entire inventory and re-calculate the time series. Otherwise, positive or negative trends in C stocks or biomass burning may be partly due to changes associated with the inventory methods at some point in the time series, and not representative of actual trends.

It is possible that new country-specific information may not be available for the entire time series. In those cases, it is *good practice* to demonstrate the effect of changes in activity levels versus updated country-specific data or methods. Guidance on recalculation for these circumstances is presented in Chapter 5 of Volume 1.

Tier 3

Similar to Tiers 1 and 2, it is *good practice* to apply the country-specific estimation system throughout the entire time series. Inventory agencies should use the same measurement protocols (sampling strategy, method, etc.) and/or model-based system throughout the inventory time period.

5.4.3 Quality Assurance and Quality Control

Tier 1

It is *good practice* to implement Quality Assurance/Quality Controls with internal and external review of Cropland inventory data. Internal reviews should be conducted by the agency in charge of the inventory, while external review is conducted by other agencies, experts or groups who are not directly involved with the compilation.

Internal review should focus on the inventory implementation process to ensure that: 1) activity data have been stratified appropriately by climate regions and soil types; 2) management classifications/descriptions have been applied appropriately; 3) activity data have been properly transcribed into the worksheets or inventory computation software; and 4) C stock change factors, reference soil C stocks, residue estimates (fuel load), and biomass burning combustion and emission factors have been assigned appropriately. Quality Assurance/Quality Control measures may involve visual inspection as well as built-in program functions to check data entry and results. Summary statistics can also be helpful, such as summing areas by strata within worksheets to determine if they are consistent with land-use statistics. Total areas should remain constant over the inventory period, and areas by strata should only vary by land-use or management classification (climate and soil areas should remain constant).

External reviews need to consider the validity of the inventory approach, thoroughness of inventory documentation, methods explanation and overall transparency. It is important to evaluate if the total area of cropland is realistic, and reviewers should cross-check area estimates across land-use categories (i.e., Forest Land, Cropland, Grassland, etc.) to ensure that the sum of the entire land base for a country is equal across every year in the inventory time period.

Tier 2

In addition to the Quality Assurance/Quality Controls measures under Tier 1, the inventory agency should review the country-specific climate regions, soil types, management system classifications, C stock change factors, reference C stocks, residue estimates (fuel load), combustion factors and/or non-CO_2 emission factors for biomass burning. If using factors based on direct measurements, the inventory agency should review the measurements to ensure that they are representative of the actual range of environmental and management conditions, and were developed according to recognized standards (IAEA, 1992). If accessible, it is *good practice* to compare country-specific factors with Tier 2 stock change and emission factors used by other countries with comparable circumstances, in addition to the IPCC defaults.

Given the complexity of emission and removal trends, specialist in the field should be involved in the external review to critique the residue fuel load estimates, stock change factors, combustion and emission factors, as well as country-specific climate regions, soil types, and/or management system descriptions.

Tier 3

Country-specific inventory systems will likely need additional Quality Assurance/Quality Control measures, but this will be dependent on the systems that are developed. It is *good practice* to develop a Quality Assurance/Quality Control protocol that is specific to the country's advanced inventory system, archive the reports, and include summary results in reporting documentation.

5.4.4 Reporting and Documentation

Tier 1

In general, it is *good practice* to document and archive all information required to produce the national inventory estimates. For Tier 1, inventory compilers should document activity data trends and uncertainties for croplands. Key activities include land-use change, use of mineral fertilizers, agroforestry practices, organic amendments, tillage management, cropping rotations, residue management (including burning), irrigation practices, extent of mixed cropping systems, water management in rice systems, and land-use change.

It is *good practice* to archive actual databases, such as agricultural census data, and procedures used to process the data (e.g., statistical programs); definitions used to categorize or aggregate activity data; and procedures used to stratify activity data by climate regions and soil types (for Tier 1 and Tier 2). The worksheets or inventory software should be archived with input/output files that were generated to produce the results.

In cases where activity data are not available directly from databases or multiple data sets were combined, the information, assumptions and procedures that were used to derive the activity data should be described. This documentation should include the frequency of data collection and estimation, and uncertainty. Use of expert knowledge should be documented and correspondences archived.

It is *good practice* to document and explain trends in biomass and soil C stocks, as well as biomass burning in terms of the land-use and management activity. Changes in biomass stocks should be linked directly to land use or changes in agroforestry practices, while trends in soil C stocks may be due to land use or shifts in key management activities, as described above. Biomass burning emissions from residues will depend on the extent to which burning is used to prepare fields for planting. Significant fluctuations in emissions between years should be explained.

Countries need to include documentation on completeness of their inventory, issues related to time series consistency or lack thereof, and a summary of Quality Assurance/Quality Control measures and results.

Tier 2
In addition to the Tier 1 considerations, inventory compilers should document the underlying basis for country-specific C stock change factors, reference soil C stocks, residue estimated (fuel loads), combustion and emission factors for biomass burning, management system classifications, climate regions and/or soil types. Furthermore, it is *good practice* to archive metadata and data sources for information used to estimate country-specific values.

Reporting documentation should include the country-specific factors (i.e., means and uncertainties). It is *good practice* to include a discussion in the inventory report about differences between country-specific factors and Tier 1 defaults as well as Tier 2 factors from regions with similar circumstances as the reporting country. If different emission factors, parameters and methods are used for different years, the reasons for these changes should be explained and documented. In addition, inventory agencies should describe country-specific classifications of management, climate and/or soil types, and it is recommended that improvements in the inventory methods based on the new classifications be documented. For example, tillage management practices may be subdivided into additional categories beyond the Tier 1 classes (i.e., reduced, no-till and full tillage), but further subdivisions will only improve inventory estimates if the stock change or emission factors differ significantly among the new categories.

When discussing trends in emissions and removals, a distinction should be made between changes in activity levels and changes in methods from year to year, and the reasons for these changes need to be documented.

Tier 3
Tier 3 inventory will need similar documentation about activity data and emission/removal trends as lower tier approaches, but additional documentation should be included to explain the underlying basis and framework of the country-specific estimation system. With measurement-based inventories, it is *good practice* to document the sampling design, laboratory procedures and data analysis techniques. Measurement data should be archived, along with results from data analyses. For Tier 3 approaches that use models, it is *good practice* to document the model version and provide a model description, as well as permanently archive copies of all model input files, source code and executable programs.

5.5 METHANE EMISSIONS FROM RICE CULTIVATION

Anaerobic decomposition of organic material in flooded rice fields produces methane (CH_4), which escapes to the atmosphere primarily by transport through the rice plants (Takai, 1970; Cicerone and Shetter, 1981; Conrad, 1989; Nouchi *et al*., 1990). The annual amount of CH_4 emitted from a given area of rice is a function of the number and duration of crops grown, water regimes before and during cultivation period, and organic and inorganic soil amendments (Neue and Sass, 1994; Minami, 1995). Soil type, temperature, and rice cultivar also affect CH_4 emissions.

These new guidelines for computing CH_4 emissions incorporate various changes as compared to the *1996 Guidelines* and the *GPG2000*, namely (i) revision of emission and scaling factors derived from updated analysis of available data, (ii) use of daily – instead of seasonal – emission factors to allow more flexibility in separating cropping seasons and fallow periods, (iii) new scaling factors for water regime before the cultivation period and timing of straw incorporation, and (iv) inclusion of Tier 3 approach in line with the general principles of the 2006 revision of guidelines. The revised guidelines also maintain the separate calculation of N_2O emission from rice cultivation (as one form of managed soil) which is dealt with in Chapter 11.

5.5.1 Choice of method

The basic equation to estimate CH_4 emissions from rice cultivation is shown in Equation 5.1. CH_4 emissions are estimated by multiplying daily emission factors by cultivation period[3] of rice and annual harvested areas[4]. In its

[3] In the case of a ratoon crop, 'cultivation period' should be extended by the respective number of days.

most simple form, this equation is implemented using national activity data (i.e., national average cultivation period of rice and area harvested) and a single emission factor. However, the natural conditions and agricultural management of rice production may be highly variable within a country. It is *good practice* to account for this variability by disaggregating national total harvested area into sub-units (e.g., harvested areas under different water regimes). Harvested area for each sub-unit is multiplied by the respective cultivation period and emission factor that is representative of the conditions that define the sub-unit (Sass, 2002). With this disaggregated approach, total annual emissions are equal to the sum of emissions from each sub-unit of harvested area.

EQUATION 5.1
CH_4 EMISSIONS FROM RICE CULTIVATION

$$CH_{4\ Rice} = \sum_{i,j,k} (EF_{i,j,k} \bullet t_{i,j,k} \bullet A_{i,j,k} \bullet 10^{-6})$$

Where:

$CH_{4\ Rice}$ = annual methane emissions from rice cultivation, Gg CH_4 yr^{-1}

EF_{ijk} = a daily emission factor for *i*, *j*, and *k* conditions, kg CH_4 ha^{-1} day^{-1}

t_{ijk} = cultivation period of rice for *i*, *j*, and *k* conditions, day

A_{ijk} = annual harvested area of rice for *i*, *j*, and *k* conditions, ha yr^{-1}

i, *j*, and *k* = represent different ecosystems, water regimes, type and amount of organic amendments, and other conditions under which CH_4 emissions from rice may vary

The different conditions that should be considered include rice ecosystem type, flooding pattern before and during cultivation period, and type and amount of organic amendments. Other conditions such as soil type, and rice cultivar can be considered for the disaggregation if country-specific information about the relationship between these conditions and CH_4 emissions are available. The rice ecosystem types and water regimes during cultivation period are listed in Table 5.12. If the national rice production can be subdivided into climatic zones with different production systems (e.g., flooding patterns), Equation 5.1 should be applied to each region separately. The same applies if rice statistics or expert judgments are available to distinguish management practices or other factors along administrative units (district or province). In addition, if more than one crop is harvested during a given year, emissions should be estimated for each cropping season taking into account possible differences in cultivation practice (e.g., use of organic amendments, flooding pattern before and during the cultivation period).

The decision tree in Figure 5.2 guides inventory agencies through the process of applying the *good practice* IPCC approach. Implicit in this decision tree is a hierarchy of disaggregation in implementing the IPCC method. Within this hierarchy, the level of disaggregation utilised by an inventory agency will depend upon the availability of activity and emission factor data, as well as the importance of rice as a contributor to its national greenhouse gas emissions. The specific steps and variables in this decision tree, and the logic behind it, are discussed in the text that follows the decision tree.

Tier 1

Tier 1 applies to countries in which either CH_4 emissions from rice cultivation are not a key category or country-specific emission factors do not exist. The disaggregation of the annual harvest area of rice needs to be done for at least three baseline water regimes including irrigated, rainfed, and upland. It is encouraged to incorporate as many of the conditions (*i*, *j*, *k*, etc.) that influence CH_4 emissions (summarized in Box 5.2) as possible. Emissions for each sub-unit are adjusted by multiplying a baseline default emission factor (for field with no pre-season flooding for less than 180 days prior to rice cultivation and continuously flooded fields without organic amendments, EF_c) by various scaling factors as shown in Equation 5.2. The calculations are carried out for each water regime and organic amendment separately as shown in Equation 5.1.

[4] In case of multiple cropping during the same year, 'harvested area' is equal to the sum of the area cultivated for each cropping.

BOX 5.2
CONDITIONS INFLUENCING CH_4 EMISSIONS FROM RICE CULTIVATION

The following rice cultivation characteristics should be considered in calculating CH_4 emissions as well as in developing emission factors:

Regional differences in rice cropping practices: If the country is large and has distinct agricultural regions with different climate and/or production systems (e.g., flooding patterns), a separate set of calculations should be performed for each region.

Multiple crops: If more than one crop is harvested on a given area of land during the year, and the growing conditions vary among cropping seasons, calculations should be performed for each season.

Water regime: In the context of this chapter, water regime is defined as a combination of (i) ecosystem type and (ii) flooding pattern.

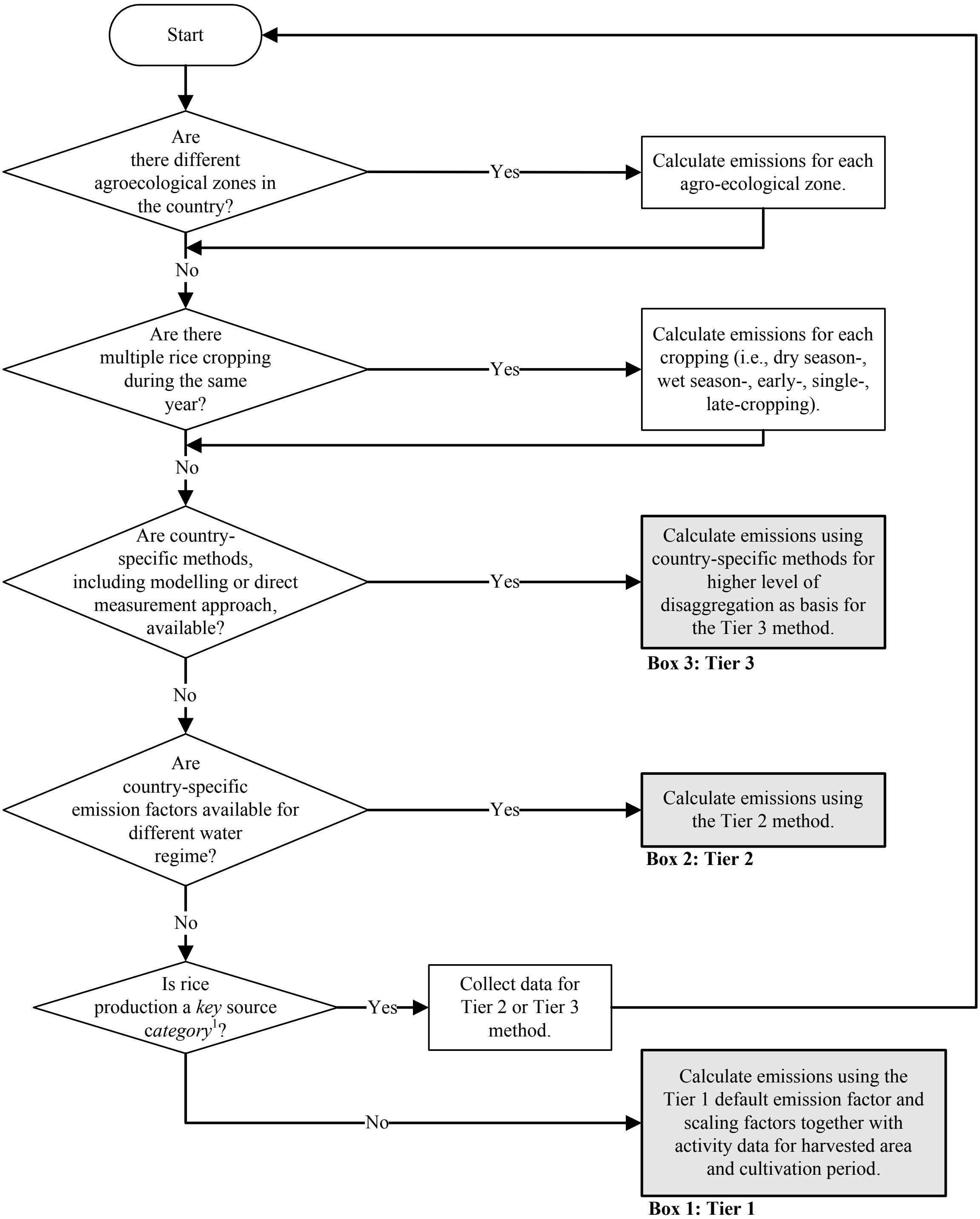
Ecosystem type: At a minimum, separate calculations should be undertaken for each rice ecosystem (i.e., irrigated, rainfed, and deep water rice production).

Flooding pattern: Flooding pattern of rice fields has a significant effect on CH_4 emissions (Sass *et al*., 1992; Yagi *et al*., 1996; Wassmann *et al*., 2000). Rice ecosystems can further be distinguished into continuously and intermittently flooded (irrigated rice), and regular rainfed, drought prone, and deep water (rainfed), according to the flooding patterns during the cultivation period. Also, flooding pattern before cultivation period should be considered (Yagi *et al*., 1998; Cai *et al*., 2000; 2003a; Fitzgerald *et al*., 2000).

Organic amendments to soils: Organic material incorporated into rice soils increases CH_4 emissions (Schütz *et al*., 1989; Yagi and Minami, 1990; Sass *et al*., 1991). The impact of organic amendments on CH_4 emissions depends on type and amount of the applied material which can be described by a dose response curve (Denier van der Gon and Neue, 1995; Yan *et al*., 2005). Organic material incorporated into the soil can either be of endogenous (straw, green manure, etc.) or exogenous origin (compost, farmyard manure, etc.). Calculations of emissions should consider the effect of organic amendments.

Other conditions: It is known that other factors, such as soil type (Sass *et al*., 1994; Wassmann *et al*., 1998; Huang *et al*., 2002), rice cultivar (Watanabe and Kimura, 1998; Wassmann and Aulakh, 2000), sulphate containing amendments (Lindau *et al*., 1993; Denier van der Gon and Neue, 2002), etc., can significantly influence CH_4 emissions. Inventory agencies are encouraged to make every effort to consider these conditions if country-specific information about the relationship between these conditions and CH_4 emissions is available.

Figure 5.2 Decision tree for CH_4 emissions from rice production



Note:
1: See Volume 1 Chapter 4, "Methodological Choice and Identification of Key Categories" (noting Section 4.1.2 on limited resources), for discussion of *key categories* and use of decision trees.

EQUATION 5.2
ADJUSTED DAILY EMISSION FACTOR

$$EF_i = EF_c \bullet SF_w \bullet SF_p \bullet SF_o \bullet SF_{s,r}$$

Where:

EF_i = adjusted daily emission factor for a particular harvested area

EF_c = baseline emission factor for continuously flooded fields without organic amendments

SF_w = scaling factor to account for the differences in water regime during the cultivation period (from Table 5.12)

SF_p = scaling factor to account for the differences in water regime in the pre-season before the cultivation period (from Table 5.13)

SF_o = scaling factor should vary for both type and amount of organic amendment applied (from Equation 5.3 and Table 5.14)

$SF_{s,r}$ = scaling factor for soil type, rice cultivar, etc., if available

Tier 2

Tier 2 applies the same methodological approach as Tier 1, but country-specific emission factors and/or scaling factors should be used. These country-specific factors are needed to reflect the local impact of the conditions (*i*, *j*, *k*, etc.) that influence CH_4 emissions, preferably being developed through collection of field data. As for Tier 1 approach, it is encouraged to implement the method at the most disaggregated level and to incorporate the multitude of conditions (*i*, *j*, *k*, etc.) that influence CH_4 emissions.

Tier 3

Tier 3 includes models and monitoring networks tailored to address national circumstances of rice cultivation, repeated over time, driven by high-resolution activity data and disaggregated at sub-national level. Models can be empirical or mechanistic, but must in either case be validated with independent observations from country or region-specific studies that cover the range of rice cultivation characteristics (Cai *et al*., 2003b; Li *et al*., 2004; Huang *et al*., 2004). Proper documentation of the validity and completeness of the data, assumptions, equations and models used is therefore critical. Tier 3 methodologies may also take into account inter-annual variability triggered by typhoon damage, drought stress, etc. Ideally, the assessment should be based on recent satellite data.

5.5.2 Choice of emission and scaling factors

Tier 1

A baseline emission factor for no flooded fields for less than 180 days prior to rice cultivation and continuously flooded during the rice cultivation period without organic amendments (EF_c) is used as a starting point. The IPCC default for EF_c is 1.30 kg CH_4 ha^{-1} day^{-1} (with error range of 0.80 - 2.20, Table 5.11), estimated by a statistical analysis of available field measurement data (Yan *et al*., 2005, the data set used in the analysis is available at a web site[5]).

Scaling factors are used to adjust the EF_c to account for the various conditions discussed in Box 5.2, which result in adjusted daily emission factors (EF_i) for a particular sub-unit of disaggregated harvested area according to Equation 5.2. The most important scaling factors, namely water regime during and before cultivation period and organic amendments, are represented in Tables 5.12, 5.13, and 5.14, respectively, through default values. Country-specific scaling factors should only be used if they are based on well-researched and documented measurement data. It is encouraged to consider soil type, rice cultivar, and other factors if available.

[5] http://www.jamstec.go.jp/frcgc/

TABLE 5.11
DEFAULT CH_4 BASELINE EMISSION FACTOR ASSUMING NO FLOODING FOR LESS THAN 180 DAYS PRIOR TO RICE CULTIVATION, AND CONTINUOUSLY FLOODED DURING RICE CULTIVATION WITHOUT ORGANIC AMENDMENTS

	Emission factor	Error range
CH_4 emission (kg CH_4 ha^{-1} d^{-1})	1.30	0.80 - 2.20

Source: Yan et al., 2005

Water regime during the cultivation period (SF_w): Table 5.12 provides default scaling factors and error ranges reflecting different water regimes. The aggregated case refers to a situation when activity data are only available for rice ecosystem types, but not for flooding patterns (see Box 5.2). In the disaggregated case, flooding patterns can be distinguished in the form of three subcategories as shown in Table 5.12. It is *good practice* to collect more disaggregated activity data and apply disaggregated case SF_w whenever possible.

TABLE 5.12
DEFAULT CH_4 EMISSION SCALING FACTORS FOR WATER REGIMES DURING THE CULTIVATION PERIOD RELATIVE TO CONTINUOUSLY FLOODED FIELDS

Water regime		Aggregated case		Disaggregated case	
		Scaling factor (SF_w)	Error range	Scaling factor (SF_w)	Error range
Upland [a]		0	-	0	-
Irrigated [b]	Continuously flooded	0.78	0.62 - 0.98	1	0.79 - 1.26
	Intermittently flooded – single aeration			0.60	0.46 - 0.80
	Intermittently flooded – multiple aeration			0.52	0.41 - 0.66
Rainfed and deep water [c]	Regular rainfed	0.27	0.21 - 0.34	0.28	0.21 - 0.37
	Drought prone			0.25	0.18 - 0.36
	Deep water			0.31	ND

ND: not determined

[a] Fields are never flooded for a significant period of time.

[b] Fields are flooded for a significant period of time and water regime is fully controlled.

• Continuously flooded: Fields have standing water throughout the rice growing season and may only dry out for harvest (end-season drainage).

• Intermittently flooded : Fields have at least one aeration period of more than 3 days during the cropping season.

- Single aeration: Fields have a single aeration during the cropping season at any growth stage (except for end-season drainage).

- Multiple aeration: Fields have more than one aeration period during the cropping season (except for end-season drainage).

[c] Fields are flooded for a significant period of time and water regime depends solely on precipitation.

• Regular rainfed: The water level may rise up to 50 cm during the cropping season.

• Drought prone: Drought periods occur during every cropping season.

• Deep water rice: Floodwater rises to more than 50 cm for a significant period of time during the cropping season.

Note: Other rice ecosystem categories, like swamps and inland, saline or tidal wetlands may be discriminated within each sub-category.

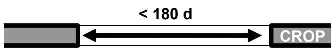
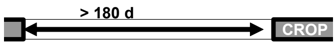
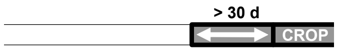
Source: Yan *et al*., 2005

Water regime before the cultivation period (SF_p): Table 5.13 provides default scaling factors for water regime before the cultivation period which can be used when country-specific data are unavailable. This table distinguishes three different water regimes prior to rice cultivation, namely:

1. Non-flooded pre-season < 180 days, which often occurs under double cropping of rice;
2. Non-flooded pre-season > 180 days, e.g., single rice crop following a dry fallow period; and
3. Flooded pre-season in which the minimum flooding interval is set to 30 days; i.e., shorter flooding periods (usually done to prepare the soil for ploughing) will not be included in this category.

When activity data for the pre-season water status are not available, aggregated case factors can be used. It is *good practice* to collect more disaggregated activity data and apply disaggregated case of SF_p. Scaling factors for additional water regimes can be applied if country-specific data are available.

TABLE 5.13
DEFAULT CH_4 EMISSION SCALING FACTORS FOR WATER REGIMES BEFORE THE CULTIVATION PERIOD

Water regime prior to rice cultivation (schematic presentation showing flooded periods as shaded)		Aggregated case		Disaggregated case	
		Scaling factor (SF_p)	Error range	Scaling factor (SF_p)	Error range
Non flooded pre-season <180 d				1	0.88 - 1.14
Non flooded pre-season >180 d		1.22	1.07 - 1.40	0.68	0.58 - 0.80
Flooded pre-season (>30 d)[a,b]				1.90	1.65 - 2.18

[a] Short pre-season flooding periods of less than 30 d are not considered in selection of SFp

[b] For calculation of pre-season emission see below (section on completeness)

Source: Yan *et al*., 2005

Organic amendments (SF_o): It is *good practice* to develop scaling factors that incorporate information on the type and amount of organic amendment applied (compost, farmyard manure, green manure, and rice straw). On an equal mass basis, more CH_4 is emitted from amendments containing higher amounts of easily decomposable carbon and emissions also increase as more of each organic amendment is applied. Equation 5.3 and Table 5.14 present an approach to vary the scaling factor according to the amount of different types of amendment applied. Rice straw is often incorporated into the soil after harvest. In the case of a long fallow after rice straw incorporation, CH_4 emissions in the ensuing rice-growing season will be less than the case that rice straw is incorporated just before rice transplanting (Fitzgerald *et al*., 2000). Therefore, the timing of rice straw application was distinguished. An uncertainty range of 0.54-0.64 can be adopted for the exponent 0.59 in Equation 5.3.

EQUATION 5.3
ADJUSTED CH_4 EMISSION SCALING FACTORS FOR ORGANIC AMENDMENTS

$$SF_o = \left(1 + \sum_i ROA_i \bullet CFOA_i\right)^{0.59}$$

Where:

SF_o = scaling factor for both type and amount of organic amendment applied

ROA_i = application rate of organic amendment *i*, in dry weight for straw and fresh weight for others, tonne ha^{-1}

$CFOA_i$ = conversion factor for organic amendment *i* (in terms of its relative effect with respect to straw applied shortly before cultivation) as shown in Table 5.14.

TABLE 5.14
DEFAULT CONVERSION FACTOR FOR DIFFERENT TYPES OF ORGANIC AMENDMENT

Organic amendment	Conversion factor (CFOA)	Error range
Straw incorporated shortly (<30 days) before cultivation[a]	1	0.97 - 1.04
Straw incorporated long (>30 days) before cultivation[a]	0.29	0.20 - 0.40
Compost	0.05	0.01 - 0.08
Farm yard manure	0.14	0.07 - 0.20
Green manure	0.50	0.30 - 0.60

[a] Straw application means that straw is incorporated into the soil, it does not include case that straw just placed on the soil surface, nor that straw was burnt on the field.

Source: Yan *et al.,* 2005

Soil type (SF_s) and rice cultivar (SF_r): In some countries emission data for different soil types and rice cultivar are available and can be used to derive SF_s and SF_r, respectively. Both experiments and mechanistic knowledge confirm the importance of these factors, but large variations within the available data do not allow one to define reasonably accurate default values. It is anticipated that in the near future simulation models will be capable of producing specific scaling factors for SF_s and SF_r.

Tier 2

Inventory agencies can use country-specific emission factors from field measurements that cover the conditions of rice cultivation in their respective country. It is *good practice* to compile country-specific data bases on available field measurements which supplement the Emission Factor database[6] by other measurement programs (e.g., national) not yet included in this data base. However, certain standard QA/QC requirements apply to these field measurements (see Section 5.5.5).

In Tier 2, inventory agencies can define the baseline management according to the prevailing conditions found in their respective country and determine country-specific emission factors for such a baseline. Then, inventory agencies can also determine country-specific scaling factors for management practices other than the baseline. In case where country-specific scaling factors are not available, default scaling factors can be used. However, this may require some recalculation of the scaling factors given in Tables 5.12 to 5.14 if the condition is different from the baseline.

Tier 3

Tier 3 approaches do not require choice of emission factors, but are instead based on a thorough understanding of drivers and parameters (see above).

5.5.3 Choice of activity data

In addition to the essential activity data requested above, it is *good practice* to match data on organic amendments and soil types to the same level of disaggregation as the activity data. It may be necessary to complete a survey of cropping practices to obtain data on the type and amount of organic amendments applied.

Activity data are primarily based on harvested area statistics, which should be available from a national statistics agency as well as complementary information on cultivation period and agronomic practices. The activity data should be broken down by regional differences in rice cropping practices or water regime (see Box 5.2). Harvested area estimates corresponding to different conditions may be obtained on a countrywide basis through accepted methods of reporting. The use of locally verified areas would be most valuable when they are correlated with available data for emission factors under differing conditions such as climate, agronomic practices, and soil properties. If these data are not available in-country, they can be obtained from international data sources: e.g., IRRI (1995) and the World Rice Statistics on the website of IRRI[7] (International Rice Research Institute), which include harvest area of rice by ecosystem type for major rice producing counties, a rice crop calendar for each country, and other useful information, and the FAOSTAT on the website of FAO[8].

[6] http://www.jamstec.go.jp/frcgc/

[7] http://www.irri.org/science/ricestat/

[8] http://faostat.fao.org/

The use of locally verified areas would be most valuable when they are correlated with available data for emission factors under differing conditions such as climate, agronomic practices, and soil properties. It may be necessary to consult local experts for a survey of agronomic practices relevant to methane emissions (organic amendments, water management, etc.).

Most likely, activity data will be more reliable as compared to the accuracy of the emission factors. However, for various reasons the area statistics may be biased and a check of the harvested area statistics for (parts of) the country with remotely sensed data is encouraged.

In addition to the essential activity data requested above, it is *good practice*, particularly in Tiers 2 and 3 approaches, to match data on organic amendments and other conditions, e.g., soil types, to the same level of disaggregation as the activity data.

5.5.4 Uncertainty assessment

The general principles of uncertainty assessment relevant for national emission inventories are elucidated in Volume 1, Chapter 3. The uncertainty of emission and scaling factors may be influenced by natural variability, such as annual climate variability, and variability within units that are assumed to be homogenous, such as spatial variability in a field or soil unit. For this source category, *good practice* should permit determination of uncertainties using standard statistical methods when enough experimental data are available. Studies to quantify some of this uncertainty are rare but available (e.g., for soil type induced variability). The variability found in such studies is assumed to be generally valid. For more detail, see Sass (2002).

Important activity data necessary to assign scaling factors (i.e., data on cultural practices and organic amendments) may not be available in current databases/statistics. Estimates of the fraction of rice farmers using a particular practice or amendment must then be based on expert judgement, and the uncertainty range in the estimated fraction should also be based on expert judgement. As a default value for the uncertainty in the fraction estimate as ± 0.2 (e.g., the fraction of farmers using organic amendment estimated at 0.4, the uncertainty range being 0.2 - 0.6). Volume 1, Chapter 3 provides advice on quantifying uncertainties in practice including combining expert judgements and empirical data into overall uncertainty estimates.

In the case of CH_4 emissions from rice cultivation, the uncertainty ranges of Tier 1 values (emission and scaling factors) can be adopted directly from Tables 5.11-5.14. Ranges are defined as the standard deviation about the mean, indicating the uncertainty associated with a given default value for this source category. The exponent in Equation 5.3 is provided with an uncertainty range of 0.54 - 0.64. Uncertainty assessment of Tier 2 and Tier 3 approaches will depend on the respective data base and model used. Therefore, it is *good practice* to apply general principles of statistical analysis as outlined in Volume 1, Chapter 3 as well as model approaches as outlined in Volume 4, Chapter 3, Section 3.5.

5.5.5 Completeness, Time series, QA/QC, and Reporting

COMPLETENESS

Complete coverage for this source category requires estimation of emissions from the following activities, where present:

- If soil submergence is not limited to the actual rice growing season, emissions outside of the rice growing season should be included (e.g., from a flooded fallow period). For further information, see Yagi *et al*., 1998; Cai *et al*., 2000; and Cai *et al*. 2003a;
- Other rice ecosystem categories, like swamp, inland-saline or tidal rice fields may be discriminated within each sub-category according to local emission measurements;
- If more than one rice crop is grown annually, these rice crops should be reported independently according to the local definition (e.g., early rice, late rice, wet season rice, dry season rice). The rice crops may fall into different categories with a different seasonally integrated emission factor and different correction factors for other modifiers like organic amendments.

DEVELOPING A CONSISTENT TIME SERIES

As for other sources and categories, the methods for estimating CH_4 emissions from rice fields should be applied consistently to every year in the time series and at the same level of disaggregation. If detailed activity level data are unavailable for earlier years, emissions for these years should be recalculated according to the guidance provided in Volume 1, Chapter 5. If there have been significant changes in agricultural practices affecting CH_4 emissions over the time series, the estimation method should be implemented at a level of disaggregation which is sufficient to discern the effects of these changes. For example, various trends in (Asian) rice agriculture such as the adoption of new rice varieties, increasing use of inorganic fertiliser, improved water management, changing use of organic amendments, and direct seeding may lead to increases or decreases in overall emissions. To weigh the impact of these changes, it may be necessary to use model studies.

REPORTING AND DOCUMENTATION

It is *good practice* to document and archive all information required to produce the national emissions inventory estimates as outlined in Volume 1, Chapter 8. It is *good practice* to document the emission estimate by reporting the information required to fill out the rice worksheet in the *Guidelines*. Inventory agencies that do not use the worksheets should provide comparable information. If the emission estimate is disaggregated by region, information on each region should be reported.

The following additional information should be reported, if available, to ensure transparency:

- Water management practices;
- The types and amounts of organic amendments used. (Incorporation of rice straw or residues of the previous (non-rice) crop should be considered an organic amendment, although it may be a normal production practice and not aimed at increasing nutrient levels as is the case with manure additions);
- Soil types used for rice agriculture;
- Number of rice crops grown annually; and
- Most important rice cultivars grown.

Inventory agencies using country-specific emission factors should provide information on the origin and basis of each factor, compare them to other published emission factors, explain any significant differences, and attempt to place bounds on the uncertainties.

INVENTORY QUALITY ASSESSMENT/QUALITY CONTROL (QA/QC)

It is *good practice* to implement quality control checks as outlined in Volume 1, Chapter 6, and expert review of the emission estimates. Additional quality control checks as outlined in Tier 2 procedures in Volume 1, Chapter 6, and quality assurance procedures may also be applicable, particularly if higher tier methods are used to determine emissions from this source.

A detailed treatment of inventory QA/QC for field measurement is given by Sass (2002). Some important issues are highlighted and summarised below.

Measurements of standard methane emissions: The inventory QC procedures used at the rice field level will be determined largely by local scientists. There are, however, certain internationally determined procedures to obtain ‘standard emission factors’ that should be common to all monitoring programmes. Instructions for obtaining standard emission factors are contained in IAEA (1992) and IGAC (1994). It is desirable for each laboratory in every reporting country to obtain this standard emission factor to ensure the intercomparibility and intercalibration of extended data sets used to establish country-specific emission factors.

Compiling national emissions: Before accepting emissions data, the inventory agency should carry out an assessment of data quality and sampling procedures. This type of review requires close cooperation with national laboratories to obtain enough information to verify the reported emissions. The assessment should include sample recalculations, an assessment on reliability of agronomic and climate data, an identification of potential bias in the methodology, and recommendations for improvement.

It is, at present, not possible to cross-check emissions estimates from this source category through external measurements. However, the inventory agency should ensure that emissions estimates undergo quality control by:

- Cross-referencing aggregated crop yield and reported field area statistics with national totals or other sources of crop yield/area data;
- Back-calculating national emission factors from aggregated emissions and other data; and
- Cross-referencing reported national totals with default values and data from other countries.

Annex 5A.1 Estimation of default stock change factors for mineral soil C emissions/removals for cropland

Default stock change factors are provided in Table 5.5 that were computed using a global dataset of experimental results for tillage, input, set-aside, and land use. The land-use factor represents the loss of carbon that occurs after 20 years of continuous cultivation. Tillage and input factors represent the effect on C stocks after 20 years following the management change. Set-aside factors represent the effect of temporary removal of cultivated cropland from production and placing it into perennial cover for a period of time that may extend to 20 years.

Experimental data (citations provided in reference list) were analyzed in linear mixed-effects models, accounting for both fixed and random effects. Fixed effects included depth, number of years since the management change, and the type of management change (e.g., reduced tillage vs. no-till). For depth, data were not aggregated but included C stocks measured for each depth increment (e.g., 0-5 cm, 5-10 cm, and 10-30 cm) as a separate point in the dataset. Similarly, time series data were not aggregated, even though those measurements were conducted on the same plots. Consequently, random effects were used to account for the dependencies in times series data and among data points representing different depths from the same study. If significant, a country level random effect was used to assess an additional uncertainty associated with applying a global default value to a specific country (included in the default uncertainties). Data were transformed with a natural log transformation if model assumptions were not met for normality and homogeneity of variance (back-transformed values are given in the tables). Factors represent the effect of the management practice at 20 years for the top 30 cm of the soil, with the exception of the land-use factor, which represents the average loss of carbon at 20 years or longer time period following cultivation. Users of the Tier 1 method can approximate the annual change in carbon storage by dividing the inventory estimate by 20. Variance was calculated for each of the factor values, and can be used with simple error propagation methods or to construct probability distribution functions with a normal density.

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