# 3.3 CROPLAND

This section provides *Good Practice Guidance* on inventorying and reporting greenhouse gas emissions and removals in 'cropland remaining cropland (CC)' and 'land converted to cropland' (LC). 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 may include cereals, oils seeds, vegetables, root crops and forages. Perennial crops can 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.[1] 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 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 (e.g. 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, density, growth rates, and harvesting and pruning practices. Carbon stocks in soils can be significant and changes in stocks can occur in conjunction with most management practices, including crop type and rotation, tillage, drainage, residue management and organic amendments.

The conversion of other land uses into cropland can affect carbon stocks and other greenhouse gases in a variety of ways. Land-use conversions to cropland from forest land, grassland and wetlands usually result in a net loss of carbon from biomass and soils 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. 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 3.3.1 below.

For cropland remaining cropland, emissions of methane ($CH_4$) and nitrous oxide ($N_2O$) from the management of permanent agricultural lands are covered in Chapter 4 of the IPCC report on *Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories* (*GPG2000*). This report provides guidance on inventorying and reporting of $N_2O$ emissions from land-use conversions to cropland as a result of soil oxidation.

In this section, guidance on the use of basic and advanced methodologies for inventorying and reporting emissions and removals for cropland remaining cropland and land converted to cropland is provided for biomass and soil carbon pools. Methodologies follow a hierarchical tier structure where Tier 1 methods use default values, typically with limited disaggregation of area data. Tier 2 corresponds to use of country-specific coefficients and typically finer scale area disaggregation, which will reduce uncertainty in emission/removal estimates. Tier 3 methods refer to the use of country-specific approaches, which may include process models and detailed inventory measurements. Where possible, default values from the *IPCC Guidelines* are updated and new default values are provided based on the most up-to-date research findings.

## 3.3.1 Cropland Remaining Cropland

Emissions and removals from cropland remaining cropland can include two subcategories of $CO_2$ emissions/removals. Equation 3.3.1 summarises net emissions or removals of carbon from cropland remaining cropland for these subcategories: changes in carbon stocks in living biomass (Section 3.3.1.1) and changes in carbon stocks in soils (3.3.1.2). As noted above, emissions of $CH_4$ and $N_2O$ are estimated as part of the Agriculture Chapter in the *IPCC Guidelines* and *GPG2000*. Table 3.3.1 summarises the methodological tiers for each of the two subcategories covered below.

[1] As described in Chapter 2, Section 2.2 (Land categories), the IPCC does not provide a single definition for forest or other land uses. Rather, countries should determine their own definition for the purposes of inventory reporting. It is *good practice* to use clear definitions in the inventory report (include threshold values, e.g. for tree cover, land area, and tree height) and to ensure that the categorisation is consistent across inventory reports and with other land use definitions.

**EQUATION 3.3.1**
**ANNUAL CHANGE IN CARBON STOCKS IN CROPLAND REMAINING CROPLAND**

$$\Delta C_{CC} = \Delta C_{CC_{LB}} + \Delta C_{CC_{Soils}}$$

Where:

$\Delta C_{CC}$ = annual change in carbon stocks in cropland remaining cropland, tonnes C yr$^{-1}$

$\Delta C_{CC_{LB}}$ = annual change in carbon stocks in living biomass, tonnes C yr$^{-1}$

$\Delta C_{CC_{Soils}}$ = annual change in carbon stocks in soils, tonnes C yr$^{-1}$

To convert tonnes C to Gg $CO_2$, multiply the value by 44/12 and $10^{-3}$. For the convention (signs), refer to Section 3.1.7 or Annex 3A.2 (Reporting Tables and Worksheets).

**TABLE 3.3.1**
**TIER DESCRIPTIONS FOR SUBCATEGORIES UNDER CROPLAND REMAINING CROPLAND**

| Tier / Sub-categories | Tier 1 | Tier 2 | Tier 3 |
|---|---|---|---|
| Living Biomass (for perennial woody crops) | Use default coefficients for carbon accumulation and loss rates. The average area of perennial woody crops is estimated by climate region. | Use at least some country-specific values for carbon accumulation and loss rates. Use detailed annual or periodic surveys to estimate the area of land in perennial woody crops, disaggregated to scales that match the country-specific rates. Consider including belowground biomass in estimate, if data are available. May rely on alternate approach of measuring or estimating carbon stocks at two points in time, in lieu of developing rates of change in carbon stocks. | Use highly disaggregated area estimates for detailed categories of perennial woody crops (e.g., coffee, orchards, intercropping systems).<br>Applies country-specific rates or estimates of carbon stock changes in the specific perennial woody crop systems. May use a country-specific approach at fine spatial scale (e.g., modeling, measurement) provided it yields a more accurate estimate of carbon stock changes. |
| Soils | For changes in soil carbon from mineral soils use default coefficients. Areas should be stratified by climate and soil type. For changes in soil carbon from organic soils use default coefficients and stratify the areas by climatic region. For emissions from liming, use default emission factors as given in *IPCC Guidelines*. | For both mineral and organic soils use some combination of default and/or country-specific coefficients and area estimates of increasingly finer spatial resolution. For emissions from liming, use emission factors differentiated by forms of lime. | Use country-specific approach at fine spatial scale (e.g., modeling, measurement) |

## 3.3.1.1 CHANGE IN CARBON STOCKS IN LIVING BIOMASS

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, and rubber plantations, and fruit and nut orchards, and polycultures such as agroforestry systems. The basic methodology for estimating changes in woody biomass is provided in the *IPCC Guidelines* Section 5.2.2 (Changes in Forest and Other Woody Biomass Stocks) and in Section 3.2.1.1 (Changes in Carbon Stocks in Living Biomass) under Section 3.2.1 (Forest land Remaining Forest land) of this report. This section elaborates these methodologies with respect to estimating changes in carbon stocks in living biomass in cropland remaining cropland.

### 3.3.1.1.1 METHODOLOGICAL ISSUES

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.

The principal equation for total change in carbon stocks of living biomass in perennial woody crops on cropland ($\Delta C_{CC_{LB}}$) is the same as Equation 3.2.2 in Section 3.2.1 (Forest land Remaining Forest land), with the only difference being that estimates of carbon stock changes apply to aboveground biomass only because limited data are available on belowground biomass. Default growth and loss rates are given in Table 3.3.2.

**TABLE 3.3.2**
**DEFAULT COEFFICIENTS FOR ABOVEGROUND WOODY BIOMASS AND HARVEST CYCLES IN CROPPING SYSTEMS CONTAINING PERENNIAL SPECIES**

| Climate region | Aboveground 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 $ha^{-1}$) | Error range[1] |
|---|---|---|---|---|---|
| Temperate (all moisture regimes) | 63 | 30 | 2.1 | 63 | $\pm$ 75% |
| Tropical, dry | 9 | 5 | 1.8 | 9 | $\pm$ 75% |
| Tropical, moist | 21 | 8 | 2.6 | 21 | $\pm$ 75% |
| Tropical, wet | 50 | 5 | 10.0 | 50 | $\pm$ 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.

Currently, there is not sufficient information to provide a basic approach with default parameters to estimate carbon stock changes in dead organic matter pools in cropland remaining cropland.

#### 3.3.1.1.1.1 Choice of Method

To estimate change in carbon in cropland biomass ($\Delta C_{CC_{LB}}$), there are two alternative approaches: (a) estimate annual rates of growth and loss (Equation 3.2.2 in Forest land section) or (b) estimate carbon stocks at two points in time (Equation 3.2.3 also in Forest land section). The first approach is developed below as the basic Tier 1 method; it can also serve as a Tier 2 or 3 method with refinements described below. The second approach is developed as either a Tier 2 or Tier 3 method.

As described in more detail below, Tier 1 is based on highly aggregated area estimates for generic perennial woody crops using default carbon accumulation rates and carbon losses. 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. A Tier 3 estimate will use a highly disaggregated Tier 2 approach or a country-specific method involving process modeling and/or detailed measurement. 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 cropland remaining cropland is a key category and if the subcategory of living biomass is considered significant based on principles outlined in Chapter 5. Countries should use the decision tree in Figure 3.1.1 to help with the choice of method.

**Tier 1:** The basic 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 other removals (according to Equation 3.2.2. in the Forest land section). Losses are estimated by multiplying a carbon stock value by the area of cropland on which perennial woody crops are harvested or removed.

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.

At Tier 1, default factors, which are discussed in more detail in Section 3.3.1.1.1.2 and Table 3.3.2., are applied to nationally derived estimates of land areas (A in Equation 3.2.4. in Forest land section).

> **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 removed. The immature perennial woody cropland area accumulates carbon at a rate of approximately 2.6 tonnes of C $ha^{-1}$ $yr^{-1}$. The area harvested loses 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 $ha^{-1}$ $yr^{-1}$. Using equation 3.2.2, an estimated 234,000 tonnes C accumulates per year and 210,000 tonnes C are lost. The net change in carbon stocks in the tropical moist environment are 24,000 tonnes C $yr^{-1}$.

**Tier 2:** One of two alternative approaches can be used at Tier 2. In principle, either approach should yield the same answer.

The approaches include:

- Extending Tier 1 by matching more disaggregated area estimates (e.g., by specific perennial woody crop types and detailed climate regions) with at least some country-specific carbon accumulation and harvest data applicable at the same scale. Countries should prioritize development of country-specific parameters by focusing on either the most common perennial woody crops or the systems with relatively high levels of perennial woody biomass per unit of land (i.e., high carbon stocks). Guidance on developing country-specific parameters is provided in Section 3.3.1.1.1.2; or,

- Estimating total carbon stocks in perennial woody crops at regular time intervals (following Equation 3.2.3 of the Forest land section).

**Tier 3:** Tier 3 approaches are either highly disaggregated Tier 2 approaches that are parameterized with country-specific carbon stock and carbon stock change values or they are country-specific methods such as use of models or repeated measurements of stocks such as those obtained using detailed forest inventories (see Section 3.2.1.1.1). For example, well validated and species-specific growth models and detailed information on harvest and pruning practices could be used to estimate annual growth rates, analogous to Equation 3.2.2. This would require information on the area of woody biomass crops by species and age class, as well as data on climate, soil and other growth limiting conditions for specific areas. Alternatively, periodic sampling-based stock estimates (and associated models), similar to those used in detailed forest inventories could be applied to estimate stock changes as in Equation 3.2.3.

#### 3.3.1.1.1.2 Choice of Emission/Removal Factors

Emission/removal factors for this methodology include the biomass accumulation (G) and loss rates (L). Table 3.3.2 provides default values for G and L across four general climate regions based on a published review of carbon stock research on agroforestry systems (Schroeder, 1994). Additional data in Table 3.3.2 highlight underlying assumptions of the default data (e.g., time to harvest/maturity) and demonstrate how the defaults were derived. The default annual growth rate (G) is derived by dividing biomass stocks at maturity by the time from crop establishment to harvest/maturity. The default annual loss rate is equal to biomass stocks at harvest, which are assumed removed entirely in the year of removal. For an individual country, these defaults are highly uncertain as they represent generic perennial woody biomass crop systems for broad climatic regions. Woody crops vary greatly in their uses, growth and harvest rates, and degree of association with other non-woody crops and thus the application of simple default factors will only coarsely approximate carbon changes.

When using the Tier 2 approach, biomass stocks, harvest cycles and carbon accumulation rates can be estimated from country or region specific research results on perennial woody crop systems conducted by national experts. Woody crops vary greatly, from annually harvested species used for green manure and fuel wood to potentially long-lived woody crops such as fruit orchards. It is important in deriving estimates of biomass accumulation rates to recognize that net increases in biomass stocks will occur primarily during the first years following initial establishment or regrowth of the woody crops. While some longer-lived orchard crops may not be subject to a regular removal and replanting cycle, losses due to pruning and tree replacement are likely to largely offset new growth so that in mature crops net biomass stock increases will be near zero. Thus, at the country-level, net increases in biomass carbon stocks would occur primarily where the area of cropland with woody crops is increasing relative to other land uses having lower carbon stocks or where the proportion of land subject to removals is less than the average dictated by the normal harvest frequency (e.g. if the land area is dominated by young, recently established woody crops). Conversely, net biomass losses at the country-level would occur when woody crops are replaced by other annual cropland systems or when the harvest frequency of woody crops is increasing.

To further improve estimates of carbon accumulation in perennial woody crop biomass, countries may conduct field research to measure carbon stock changes or accumulation rates. Research studies should be based on sound scientific principles and follow general approaches laid out by other similar studies (Dixon *et al.*, 1993; Schroeder, 1994; Schroth *et al.*, 2002; and Masera *et al.*, 2003). Results from field research should be compared to estimates of carbon accumulation rates from other sources to verify that they are within documented ranges. Reported carbon accumulation rates may be modified based on additional data and expert opinion, provided clear rationale and documentation are included in the inventory report.

### 3.3.1.1.1.3 Choice of Activity Data

Activity data in this section refer to estimates of land areas ($A_G$, $A_L$) of growing stock and harvested land in perennial woody crops. Chapter 2 provides general guidance on approaches for obtaining and categorising area by different land use classes. For estimating emissions and removals from this source, countries need to obtain area estimates for land in perennial woody crops, disaggregated as required to correspond to the available emission factors and other parameters.

**Tier 1:** Under Tier 1, annual or periodic surveys are used in conjunction with the approaches outlined in Chapter 2 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 subdivided into general climate regions to match the default G and L values. Under Tier 1 calculations, international statistics such as FAO databases, *IPCC Guidelines* and other sources can be used to estimate the area of land in perennial woody crops.

**Tier 2:** For the Tier 2 method, 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 categories such that all major combinations of perennial woody crop types and climatic regions are represented with area estimates for each. These area estimates must match any country-specific carbon accumulation 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). If possible, spatially explicit area estimates are used to facilitate complete coverage of the perennial woody cropland and ensure that areas are not over- or underestimated. Furthermore, spatially explicit area estimates can be related to locally relevant carbon accumulation and removal rates, and restocking and management impacts, improving the accuracy of estimates.

### 3.3.1.1.1.4 Uncertainty Assessment

The following discussion provides guidance on approaches for assessing uncertainty associated with each tier method described in Section 3.3.1.1.1.1.

**Tier 1:** The sources of uncertainty when using the Tier 1 method include the degree of accuracy in land area estimates and in the default carbon accumulation and loss rates. A published compilation of research on carbon stocks in agroforestry systems was used to derive the default data provided in Section 3.3.1.1.1.2 (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 parameter value has been assigned based on expert judgement. This information can be used with a measure of uncertainty in area estimates from Chapter 2 of this Report to assess the uncertainty in estimates of carbon emissions and removals in cropland biomass using the Tier 1 methodology for uncertainty analysis in Chapter 5.2 (Identifying and quantifying uncertainties).

**Tier 2:** The Tier 2 method will reduce overall uncertainty because country-defined rates should provide more accurate estimates of carbon accumulation 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-defined carbon accumulation 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-defined 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-defined 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 reduce uncertainty levels when associated with carbon accumulation 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 growth and loss rates. It is also *good practice* to assess the measurement error in land area estimates for each land base category. Countries should consider developing probability density functions for model parameters to use in Monte Carlo simulations.

## 3.3.1.2 CHANGE IN CARBON STOCKS IN SOILS

### 3.3.1.2.1 METHODOLOGICAL ISSUES

The *IPCC Guidelines* provide methods for estimating $CO_2$ Emissions and Uptake by Soils from Land-Use and Management (Section 5.3) that can be applied to all land uses, including cropland. The methodology considers organic carbon stock changes ($CO_2$ emissions or removals) for mineral soils, $CO_2$ emissions from organic soils (i.e. peat soils) and emissions of $CO_2$ from liming of agricultural soils.

In the *IPCC Guidelines*, carbon stocks are measured to a default depth of 30cm and do not include C in surface residue (i.e. dead organic matter) or changes in inorganic carbon (i.e. carbonate minerals). In most cropland soils, surface residue is either absent (due to incorporation with tillage) or represents a minor stock. Other depths may be used at higher tiers, but depth must in all cases be used consistently over time.

The summary Equation 3.3.2 for estimating the change in organic carbon stocks in soils is shown below:

**EQUATION 3.3.2**
**ANNUAL CHANGE IN CARBON STOCKS IN SOILS IN CROPLAND REMAINING CROPLAND**

$$\Delta C_{CC_{Soils}} = \Delta C_{CC_{Mineral}} - \Delta C_{CC_{Organic}} - \Delta C_{CC_{Lime}}$$

Where:

$\Delta C_{CC_{Soils}}$ = annual change in carbon stocks in soils in cropland remaining cropland, tonnes C $yr^{-1}$

$\Delta C_{CC_{Mineral}}$ = annual change in carbon stocks in mineral soils, tonnes C $yr^{-1}$

$\Delta C_{CC_{Organic}}$ = annual carbon emissions from cultivated organic soils (estimated as net annual flux), tonnes C $yr^{-1}$

$\Delta C_{CC_{Lime}}$ = annual C emissions from agricultural lime application, tonnes C $yr^{-1}$

For Tiers 1 and 2 methods, changes in dead organic matter and inorganic carbon should be assumed to be zero. If dead organic matter is included in a Tier 3 approach, measurements should be based on the lowest amounts present during an annual cycle to avoid including fresh post-harvest residues that represent a transient organic matter pool. Selection of the most suitable tier will depend on: 1) type and level of detail of activity data on agricultural management and changes in management over time, 2) availability of suitable information to estimate base C stocks and stock change and emission factors, 3) availability of dedicated national inventory systems designed for soils.

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 cropland remaining cropland is a key category and if the subcategory of soil organic matter is considered significant based on principles outlined in Chapter 5. Countries should use the decision tree in Figure 3.1.1 to help with the choice of method.

#### 3.3.1.2.1.1 Choice of Method

The method used to estimate carbon stock changes in mineral soils is different from the method used for organic soils. It is also possible that countries will use different tiers to prepare estimates of the separate components on this subcategory, given availability of resources. Thus, mineral soils, organic soils, and emissions from liming are discussed separately below.

***Mineral Soils***

For mineral soils, the estimation method is based on changes in soil C stocks over a finite period following changes in management that impact soil C, as shown in Equation 3.3.3. Previous soil C stocks ($SOC_{(0-T)}$) and soil C stocks in the inventory year ($SOC_0$) for the area of a cropland system in the inventory are estimated from reference carbon stocks (Table 3.3.3) and stock change factors (Table 3.3.4), applied for the respective time points. Here a cropland system refers to a specific climate, soil and management combination. Annual rates of emissions (source) or removals (sink) are calculated as the difference in stocks (over time) divided by the inventory time period. The default time period is 20 years.

**EQUATION 3.3.3**
**ANNUAL CHANGE IN CARBON STOCKS IN MINERAL SOILS FOR A SINGLE CROPLAND SYSTEM**

$$\Delta C_{CC_{Mineral}} = [(SOC_0 - SOC_{(0-T)}) \bullet A] / T$$

$$SOC = SOC_{REF} \bullet F_{LU} \bullet F_{MG} \bullet F_I$$

Where:

$\Delta C_{CC_{Mineral}}$ = annual change in carbon stocks in mineral soils, tonnes C $yr^{-1}$

$SOC_0$ = soil organic carbon stock in the inventory year, tonnes C $ha^{-1}$

$SOC_{(0-T)}$ = soil organic carbon stock T years prior to the inventory, tonnes C $ha^{-1}$

T = inventory time period, yr (default is 20 yr)

A = land area of each parcel, ha

$SOC_{REF}$ = the reference carbon stock, tonnes C $ha^{-1}$; see Table 3.3.3

$F_{LU}$ = stock change factor for land use or land-use change type, dimensionless; see Table 3.3.4

$F_{MG}$ = stock change factor for management regime, dimensionless; see Table 3.3.4

$F_I$ = stock change factor for input of organic matter, dimensionless; see Table 3.3.4

The types of land use and management factors supplied are very broadly defined and include: 1) a land use factor ($F_{LU}$) that reflects C stock changes associated with type of land use, 2) a management factor ($F_{MG}$) that for permanent cropland represents different types of tillage and 3) an input factor ($F_I$) representing different levels of C inputs to soil. For cropland, $F_{LU}$ describes base C stocks for long-term cultivated soils, paddy rice cultivation and for temporary cropland set-asides, relative to native (uncultivated) soil C stocks. If the area was in other land use (e.g. forest land, grazing land) at the beginning of the inventory period, then guidance provided under Section 3.3.2, Land Converted to Cropland, should be followed.

The calculation steps for determining $SOC_0$ and $SOC_{(0-T)}$ and net soil C stock change per ha of land area are as follows:

**Step 1:** Select the reference carbon stock value ($SOC_{REF}$), based on climate and soil type, for each area of land being inventoried.

**Step 2:** Select the type of cropland use (long-term cultivated, paddy rice, set-aside) present at beginning of the inventory period (e.g. 20 years ago), together with tillage ($F_{MG}$) and C input levels ($F_I$). These factors, multiplied by the reference soil C stock, provide the estimate of 'initial' soil C stock ($SOC_{(0-T)}$) for the inventory period.

**Step 3:** Calculate $SOC_0$ by repeating step 2 using the same reference carbon stock ($SOC_{REF}$), but with land use, tillage and input factors that represent conditions in the (current) inventory year.

**Step 4:** Calculate the average annual change in soil C stock for the area over the inventory period ($\Delta C_{CC_{Mineral}}$)

> **Example**: For a Mollisol soil in a warm temperate moist climate, $SOC_{REF}$ is 88 tonnes C $ha^{-1}$. On an area of land under long-term annual cropping, previously managed with intensive tillage and low C input level, the carbon stock at the beginning of the inventory period is calculated as ($SOC_{REF} \bullet F_{LU} \bullet F_{MG} \bullet F_I$, ) = 88 tonnes C $ha^{-1} \bullet 0.71 \bullet 1 \bullet 0.91$ = 56.9 tonnes C $ha^{-1}$. Under the current management of annual cropping with no tillage and medium C input level the carbon stock is calculated as 88 tonnes C $ha^{-1} \bullet 0.71 \bullet 1.16 \bullet 1$ = 72.5 tonnes C $ha^{-1}$. Thus the average annual change in soil C stock for the area over the inventory period is calculated as (72.5 tonnes C $ha^{-1}$ – 56.9 tonnes C $ha^{-1}$) / 20 yrs = 0.78 tonnes C $ha^{-1}$ $yr^{-1}$.

**TABLE 3.3.3**

**DEFAULT REFERENCE (UNDER NATIVE VEGETATION) SOIL ORGANIC C STOCKS ($SOC_{REF}$)**
**(TONNES C PER HA FOR 0-30 CM DEPTH)**

| Region | HAC soils[1] | LAC soils[2] | Sandy soils[3] | Spodic soils[4] | Volcanic soils[5] | Wetland soils[6] |
|---|---|---|---|---|---|---|
| Boreal | 68 | NA | 10# | 117 | 20# | 146 |
| Cold temperate, dry | 50 | 33 | 34 | NA | 20# | 87 |
| Cold temperate, moist | 95 | 85 | 71 | 115 | 130 | |
| Warm temperate, dry | 38 | 24 | 19 | NA | 70# | 88 |
| Warm temperate, moist | 88 | 63 | 34 | NA | 80 | |
| Tropical, dry | 38 | 35 | 31 | NA | 50# | 86 |
| Tropical, moist | 65 | 47 | 39 | NA | 70# | |
| Tropical, wet | 44 | 60 | 66 | NA | 130# | |

Note: Data are derived from soil databases described by Jobbagy and Jackson (2000) and Bernoux *et al.* (2002). Mean stocks are shown. A default error estimate of 95% (expressed as 2X standard deviations as percent of the mean) are assumed for soil-climate types. NA denotes 'not applicable' because these soils do not normally occur in some climate zones.

# indicates where no data were available and default values from *IPCC Guidelines* were retained.

[1] Soils with high activity clay (HAC) minerals are lightly to moderately weathered soils, which are dominated by 2:1 silicate clay minerals (in the World Reference Base for Soil Resources (WRB) classification these include Leptosols, Vertisols, Kastanozems, Chernozems, Phaeozems, Luvisols, Alisols, Albeluvisols, Solonetz, Calcisols, Gypsisols, Umbrisols, Cambisols, Regosols; in USDA classification includes Mollisols, Vertisols, high-base status Alfisols, Aridisols, Inceptisols).

[2] Soils with low activity clay (LAC) minerals are highly weathered soils, dominated by 1:1 clay minerals and amorphous iron and aluminium oxides (in WRB classification includes Acrisols, Lixisols, Nitisols, Ferralsols, Durisols; in USDA classification includes Ultisols, Oxisols, acidic Alfisols).

[3] Includes all soils (regardless of taxonomic classification) having > 70% sand and < 8% clay, based on standard textural analyses (in WRB classification includes Arenosols,; in USDA classification includes Psamments).

[4] Soils exhibiting strong podzolization (in WRB classification includes Podzols; in USDA classification Spodosols)

[5] Soils derived from volcanic ash with allophanic mineralogy (in WRB classification Andosols; in USDA classification Andisols)

[6] Soils with restricted drainage leading to periodic flooding and anaerobic conditions (in WRB classification Gleysols; in USDA classification Aquic suborders).

**TABLE 3.3.4**
**RELATIVE STOCK CHANGE FACTORS ($F_{LU}$, $F_{MG}$, AND $F_I$) (OVER 20 YEARS) FOR DIFFERENT MANAGEMENT ACTIVITIES ON CROPLAND [SEE SECTION 3.3.7 FOR METHODS AND DATA SOURCES USED IN FACTOR DERIVATION]**

| Factor value type | Level | Temperature regime | '96 IPCC default | Moisture Regime[1] | GPG revised default | Error[2,3] | Description |
|---|---|---|---|---|---|---|---|
| Land use ($F_{LU}$) | Long-term cultivated | Temperate | 0.7,0.6[4] | Dry | 0.82 | ± 10% | 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. |
| | | | | Wet | 0.71 | ± 12% | |
| | | Tropical | 0.6, 0.5 | Dry | 0.69 | ± 38% | |
| | | | | Wet | 0.58 | ± 42% | |
| Land use ($F_{LU}$) | Paddy rice | Temperate and Tropical | 1.1 | Dry and Wet | 1.1 | ± 90% | Long-term (> 20 year) annual cropping of wetland (paddy rice). Can include double-cropping with non-flooded crops. For paddy rice, tillage and input factors are not used. |
| Land use ($F_{LU}$) | Set aside (< 20 yrs) | Temperate and Tropical | 0.8 | Dry | 0.93 | ± 10% | Represents temporary set aside of annually cropland (e.g. conservation reserves) or other idle cropland that has been revegetated with perennial grasses. |
| | | | | Wet | 0.82 | ± 18% | |
| Tillage ($F_{MG}$) | Full | Temperate | 1.0 | Dry and Wet | 1.0 | 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. |
| | | Tropical | 0.9, 0.8 | Dry and Wet | 1.0 | NA | |
| Tillage ($F_{MG}$) | Reduced | Temperate | 1.05 | Dry | 1.03 | ± 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. |
| | | | | Wet | 1.09 | ± 6% | |
| | | Tropical | 1.0 | Dry | 1.10 | ± 10% | |
| | | | | Wet | 1.16 | ± 8% | |
| Tillage ($F_{MG}$) | No-till | Temperate | 1.1 | Dry | 1.10 | ± 6% | Direct seeding without primary tillage, with only minimal soil disturbance in the seeding zone. Herbicides are typically used for weed control. |
| | | | | Wet | 1.16 | ± 4% | |
| | | Tropical | 1.1 | Dry | 1.17 | ± 8% | |
| | | | | Wet | 1.23 | ± 8% | |
| Input ($F_I$) | Low | Temperate | 0.9 | Dry | 0.92 | ± 4% | Low residue return due to removal of residues (via collection or burning), frequent bare-fallowing or production of crops yielding low residues (e.g. vegetables, tobacco, cotton) |
| | | | | Wet | 0.91 | ± 8% | |
| | | Tropical | 0.8 | Dry | 0.92 | ± 4% | |
| | | | | Wet | 0.91 | ± 4% | |
| Input ($F_I$) | Medium | Temperate | 1.0 | Dry and Wet | 1.0 | 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. |
| | | Tropical | 0.9 | Dry and Wet | 1.0 | NA | |
| Input ($F_I$) | High – without manure | Temperate and Tropical | 1.1 | Dry | 1.07 | ± 10% | Represents significantly greater crop residue inputs due to production of high residue yielding crops, use of green manures, cover crops, improved vegetated fallows, frequent use of perennial grasses in annual crop rotations, but without manure applied (see row below) |
| | | | | Wet | 1.11 | ± 10% | |
| Input ($F_I$) | High – with manure | Temperate and Tropical | 1.2 | Dry | 1.34 | ± 12% | Represents high input of crop residues together with regular addition of animal manure (see row above). |
| | | | | Wet | 1.38 | ± 8% | |

[1] Where data were sufficient, separate values were determined for temperate and tropical temperature regimes and dry and wet moisture regimes. Temperate and tropical zones correspond to those defined in the Chapter 3 introduction (3.1); wet moisture regime corresponds to the combined moist and wet zones in the tropics and wet zone temperate region (see Figure 3.1.3); dry zone is the same as defined Figure 3.1.3.

[2] ± two standard deviations, expressed as a percent of the mean; where sufficient studies were not available for a statistical analysis a default, based on expert judgement, of ± 50% is used. NA denotes 'Not Applicable', where factor values constitute defined reference values.

[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] The second value applies to the Aquic soil class as defined in the *IPCC Guidelines*. No significant differences were found for different soil types in the updated estimates produced here for the *Good Practice Guidance*.

**Tier 1:** For Tier 1, default reference carbon stocks and stock change factors are used (as shown in Equation 3.3.3) for major cropland systems in a country, stratified by the default climate and soil types (Equation 3.3.4). For the aggregate area of cropland remaining cropland, stock changes can be calculated either by tracking management changes and calculating stock changes on individual parcels of land (Equation 3.3.4B) or by calculating aggregate soil carbon stocks at the start and end of the inventory period from more general data on the area distribution of cropland systems (Equation 3.3.4A). Aggregate results will be the same with either approach, the main difference being that attribution of the effects of specific changes in management require activity data that tracks management changes on specific areas of land. Default values for this calculation are described in Section 3.3.1.2.1.2.

**EQUATION 3.3.4**

**ANNUAL CHANGE IN CARBON STOCKS IN MINERAL SOILS IN CROPLAND REMAINING CROPLAND**

$$\Delta C_{CC_{Mineral}} = \Sigma_c \Sigma_s \Sigma_i \left[ (SOC_0 - SOC_{(0-T)}) \bullet A \right]_{c,s,i} / T \qquad (A)$$

$$\Delta C_{CC_{Mineral}} = \left[ \Sigma_c \Sigma_s \Sigma_i (SOC_0 \bullet A)_{c,s,i} - \Sigma_c \Sigma_s \Sigma_i (SOC_{(0-T)} \bullet A)_{c,s,i} \right] / T \qquad (B)$$

Where:

$\Delta C_{CC_{Mineral}}$ = annual change in carbon stocks in mineral soils, tonnes C $yr^{-1}$

$SOC_0$ = soil organic carbon stock in the inventory year, tonnes C $ha^{-1}$

$SOC_{(0-T)}$ = soil organic carbon stock T years prior to the inventory, tonnes C $ha^{-1}$

T = inventory time period, yr (default is 20 yr)

A = land area of each parcel, ha

*c* represents the climate zones, *s* the soil types, and *i* the set of major cropland systems that are present in a country.

**Example**: The following example shows calculations for aggregate areas of cropland soil carbon stock change using Equation 3.3.4B. In a warm temperate moist 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 (i.e. 20 yrs earlier) 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 $ha^{-1}$ ● 0.71 ● 1 ● 0.91) + 600,000 ha ● (88 tonnes C $ha^{-1}$ ● 0.71 ● 1 ● 1) = 60.231 million tonnes C. In the (current) inventory year, 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 $ha^{-1}$ ● 0.71 ● 1 ● 0.91) + 700,000 ha ● (88 tonnes C $ha^{-1}$ ● 0.71 ● 1.09 ● 1) + 100,000 ha ● (88 tonnes C $ha^{-1}$ ● 0.71 ● 1.16 ● 1) = 66.291 million tonnes C. Thus the average annual stock change over the period for the entire area is: (66.291 – 60.231) million tonnes C / 20 yr = 6.060 million tonnes / 20 yr = 303,028 tonnes per year soil C stock increase.

**Tier 2:** For Tier 2, the same basic equations as in Tier 1 are used but country-specific values for reference carbon stocks and/or stock change factors are used. In addition, Tier 2 approaches will likely involve a more detailed stratification of management systems if sufficient data are available.

**Tier 3:** Tier 3 approaches, using a combination of dynamic models along with detailed soil C emission/stock change inventory measurements, will likely not employ simple stock change or emission factors *per se*. Estimates of emissions using model-based approaches derive from the interaction of multiple equations that estimate the net change of soil C stocks within the models. A variety of models designed to simulate soil carbon dynamics exist (for example, see reviews by McGill *et al.*, 1996; Smith *et al.*, 1997).

Key criteria in selecting an appropriate model are that the model is capable of representing all of the management practices that are represented and that model inputs (i.e. driving variables) are compatible with the availability of country-wide input data. It is critical that the model be validated with independent observations from country or region-specific field locations that are representatives of the variability of climate, soil and management systems in the country. Examples of appropriate validation data sets include long-term replicated field experiments (e.g. SOMNET, 1996; Paul *et al.*, 1997) or long-term measurements of ecosystem carbon flux for agricultural systems, using techniques such as eddy covariance (Baldocchi *et al.*, 2001). Ideally, an inventory system of permanent, statistically representative "on-farm" plots, that include major climatic regions, soil types, and management systems and system changes, would be established where repeated measures of soil carbon stocks could be made over time. Recommended re-sampling frequencies in most cases should not be less than 3 to 5 years (IPCC, 2000b). Where possible, measurements of soil carbon stocks should be made on an equivalent mass basis (e.g. Ellert *et al.*, 2001). Procedures should be implemented to minimize the influence of spatial variability with repeated sampling over time (e.g. Conant and Paustian 2002). Such inventory measurements could be integrated with a model-based methodology.

### *Organic Soils*

The basic methodology for estimating carbon stock change in organic (e.g. peat-derived) soils is to assign an annual loss rate of C due to the drainage and other perturbations such as tillage of the land for agricultural production. Drainage and tillage stimulate the oxidation of organic matter previously built up under a largely anoxic environment. The area of cropland organic soils under each climate type is multiplied by the emission factor to derive an estimate of annual C emissions, as shown in Equation 3.3.5 below:

**EQUATION 3.3.5**
**$CO_2$ EMISSIONS FROM CULTIVATED ORGANIC SOILS IN CROPLAND REMAINING CROPLAND**

$$\Delta C_{CC_{Organic}} = \sum_c (A \bullet EF)_c$$

Where:

$\Delta C_{CC_{Organic}}$ = $CO_2$ emissions from cultivated organic soils in cropland remaining cropland, tonnes C $yr^{-1}$

A = land area of organic soils in climate type *c,* ha

EF = emission factor for climate type *c* (see Table 3.3.5), tonnes C $ha^{-1}$ $yr^{-1}$

**Tier 1:** For Tier 1, default emission factors (Table 3.3.5) are used along with area estimates for cultivated organic soils within each climate region present in the country (Equation 3.3.5). Area estimates can be developed using the guidance in Chapter 2.

**Tier 2:** The Tier 2 approach uses Equation 3.3.5 where emission factors are estimated from country-specific data, stratified by climate region, as described in Section 3.3.2.1.3. Area estimates should be developed following the guidance of Chapter 2.

**Tier 3:** Tier 3 approaches for organic soils will include more detailed systems integrating dynamic models and measurement networks as described above for mineral soils.

**TABLE 3.3.5**
**ANNUAL EMISSION FACTORS (EF) FOR CULTIVATED ORGANIC SOILS**

| Climatic temperature regime | *IPCC Guidelines* default (tonnes C $ha^{-1}$ $yr^{-1}$) | Error # |
|---|---|---|
| Cold Temperate | 1.0 | $\pm$ 90% |
| Warm Temperate | 10.0 | $\pm$ 90% |
| Tropical/sub-tropical | 20.0 | $\pm$ 90% |

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

### *Liming*

The *IPCC Guidelines* include application of carbonate containing lime (e.g. calcic limestone ($CaCO_3$), or dolomite ($CaMg(CO_3)_2$) to agricultural soils as a source of $CO_2$ emissions. A simplified explanation of the process is that when carbonate lime is dissolved in soil, the base cations ($Ca^{++}$, $Mg^{++}$) exchange with hydrogen ions ($H^+$) on soil colloids (thereby reducing soil acidity) and the bicarbonate formed ($2HCO_3$) can react further to evolve $CO_2$ and water ($H_2O$). Although the liming effect generally has a duration of a few years (after which lime is again added), depending on climate, soil and cropping practices, the *IPCC Guidelines* account for emission as $CO_2$ of all the added carbonate carbon in the year of application. Thus the basic methodology is simply the amount of agricultural lime applied times an emission factor that varies slightly depending on the composition of the material added.

**EQUATION 3.3.6**
**ANNUAL CARBON EMISSIONS FROM AGRICULTURAL LIME APPLICATION**

$$\Delta C_{CC_{Lime}} = M_{Limestone} \bullet EF_{Limestone} + M_{Dolomite} \bullet EF_{Dolomite}$$

Where:

$\Delta C_{CC_{Lime}}$ = annual C emissions from agricultural lime application, tonnes C $yr^{-1}$

M = annual amount of calcic limestone ($CaCO_3$) or dolomite ($CaMg(CO_3)_2$), tonnes $yr^{-1}$

EF = emission factor, tonnes C (tonne limestone or dolomite)$^{-1}$ (These are equivalent to carbonate carbon contents of the materials (12% for $CaCO_3$, 13% for $CaMg(CO_3)_2$ )).

**Tier 1:** For Tier 1, the total amount of carbonate containing lime applied annually to cropland soil and an overall emission factor of 0.12 can be used to estimate $CO_2$ emissions, without differentiating between variable compositions of lime material. Note that while carbonate limes are the dominant liming material used, oxides and hydroxides of lime, which do not contain inorganic carbon, are used to a limited extent for agricultural liming and should not be included here ($CO_2$ is produced in their manufacture but not following soil application).

**Tier 2:** A Tier 2 approach could entail differentiation of different forms of lime and specific emission factors if data are available, since different carbonate liming materials (limestone as well as other sources such as marl and shell deposits) can vary somewhat in their carbon content and overall purity.

**Tier 3:** A Tier 3 approach could entail a more detailed accounting of emissions stemming from lime applications than is assumed under Tiers 1 and 2. Depending on climate and soil conditions, biocarbonate derived from lime application may not all be released as $CO_2$ in the soil or from drainage water – some can be leached and precipitated deeper in the soil profile or be transported to deep groundwater, lakes and oceans and sequestered. If sufficient data and understanding of inorganic carbon transformation for specific climate-soil conditions are available, specific emission factors could be derived. However, such an analysis would likely necessitate including carbon fluxes associated with primary and secondary carbonate minerals in soil and their response to agricultural management practices.

### 3.3.1.2.1.2 Choice of Emission/Removal Factors

#### *Mineral soils*

When using either the Tier 1 or Tier 2 method, the following emission/removal factors are needed for mineral soils: reference carbon stock ($SOC_{REF}$); stock change factor for land-use change ($F_{LU}$); stock change factor for management regime ($F_{MG}$); stock change factor for input of organic matter ($F_I$).

**Reference carbon stocks ($SOC_{REF}$)**

Soils under native vegetation that have not been subject to significant land use and management impacts are used as a baseline or reference to which management-induced changes in soil carbon can be related.

**Tier 1:** Under Tier 1, it is *good practice* to use the default reference carbon stocks ($SOC_{REF}$) provided in Table 3.3.3. These are updated from those provided in the *IPCC Guidelines* with the following improvements: i) estimates are statistically-derived from recent compilations of soil profiles under native vegetation, ii) 'Spodic' soils (defined as boreal and temperate zone podzols in WRB classification, Spodosols in USDA classification) are included as a separate category, iii) soils within the boreal climate region have been included.

**Tier 2:** For Tier 2, reference soil C stocks can be determined from measurements of soils, for example, as part of a country's soil survey and mapping activities. Advantages include more representative values for an individual country and the ability to better estimate probability distribution functions that can be used in a formal uncertainty analysis. Accepted standards for sampling and analysis of soil organic carbon and bulk density should be used and documented.

**Stock change factors ($F_{LU}$, $F_{MG}$, $F_I$)**

**Tier 1:** Under Tier 1, it is *good practice* to use default stock change factors **($F_{LU}$, $F_{MG}$, $F_I$)** provided in Table 3.3.4. These are updated from the *IPCC Guidelines*, based on a statistical analysis of published research. Definitions guiding the selection of appropriate factor values are provided in the table.

**Tier 2:** For the Tier 2 method, stock change factors can be estimated from long-term experiments (e.g. Smith *et al.*, 1996; Paul *et al.*, 1997) or other field measurements (e.g. field chronosequences[2]) for a particular country or region. To estimate stock change factors, information compiled from published studies and other sources should include organic C stock (i.e. mass per unit area to a specified depth) or all information needed to calculate SOC stocks, i.e. percent organic matter together with bulk density. If the percent organic matter and not the percent organic carbon are reported, a conversion factor of 0.58 for the carbon content of soil organic matter can be used. Other information that must be included is depth of measurement and time frame over which the management difference has been expressed. In the absence of specific information upon which to select an alternative depth interval, it is *good practice* to compare stock change factors at a depth of at least 30 cm (i.e. the depth used for Tier 1 calculations). Stock changes over a deeper depth may be desirable if a sufficient number of studies are available and if statistically significant differences in stocks due to land management are demonstrated at deeper depths. However, it is critical that the reference soil carbon stocks ($SOC_{Ref}$) and stock change factors be determined to a common depth. Factor values should be compiled for major climate and/or soils types, at least to the level of detail used in the Tier 1 method.

### *Organic soils*

When estimating emissions from organic soils, an emission factor (EF) is required for different climatic regimes where organic soils have been drained for cropland use.

**Tier 1:** For Tier 1, default emission factors, unchanged from the *IPCC Guidelines*, are provided in Table 3.3.5. These factors are differentiated by major climate (temperature) regimes and assume that soils have been drained prior to use as cropland. Organic soils used for paddy rice or minor crops grown under flooded conditions (e.g. cranberry bogs, wild rice) are excluded.

**Tier 2:** For Tier 2, it is possible to derive emission factors from literature data on carbon losses from organic soils. Estimates of carbon losses from cultivated organic soils are usually based on measurements of subsidence with fewer studies based on direct measurements of $CO_2$ fluxes (Klemedtsson *et al.*, 1997; Ogle *et al.*, 2003). Processes that contribute to subsidence include erosion, compaction, burning, and decomposition. Only decomposition losses should be included in the emission factor estimate. If using subsidence data, appropriate regional conversion factors to determine the proportion of subsidence attributable to oxidation should be used, based on studies measuring both subsidence and $CO_2$ flux. In the absence of such information, a default factor of 0.5 for oxidation-to-subsidence, on a gram-per-gram equivalent basis, is recommended based on a review by Armentano and Menges (1986). If available, direct measurements of carbon fluxes are recommended as providing the best means of estimating emission rates from organic soils.

### *Liming*

See Section 3.3.1.2.1.1.

## 3.3.1.2.1.3 Choice of Activity Data

### *Mineral Soils*

The area of cropland under different management practices (A) is required for estimating mineral soil emissions/removals.

For existing cropland, activity data should record changes or trends in management practices that affect soil carbon storage, such as crop types and crop rotations, tillage practices, irrigation, manure application, residue management, *etc*. Two main types of management activity data exist: 1) aggregate statistics compiled by country or for administrative areas within countries (e.g. provinces, counties) or 2) point-based land use and management inventories making up a statistically-based sample of a country's land area. Either type of activity data could be used for any of the three tiers, depending on their spatial and temporal resolution. For Tier 1 and Tier 2 inventories, activity data should be stratified by major climatic regions and soil types, since reference soil C stocks vary significantly according to these factors. For the broadly defined soil categories used in Tier 1, national or even global soil maps can be used to delineate soil divisions within the cropland land area. For application of dynamic models and/or a direct measurement-based inventory in Tier 3, similar or more detailed knowledge of the combinations of climate, soil, topographic and management data are needed, but the exact requirements will be in part dependent on the model used.

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[2] Chronosequences consist of measurements taken from similar but separate locations that represent a temporal sequence in land use or management, for example, years since deforestation. Efforts are made to control all other between-site differences (e.g. by selecting areas with similar soil type, topography, previous vegetation). Chronosequences are often used as a surrogate for experimental studies or measurements repeated over time at the same location.

Globally available land use and crop production statistics such as FAO databases (http://apps.fao.org) provide annual compilations of total land area by major land-use types, with some differentiation of management systems, (e.g., irrigated vs. non-irrigated cropland), area in 'permanent' crops (i.e. vineyards, orchards), and land area and production for major crops (e.g. wheat, rice, maize, sorghum, etc.). Thus FAO or similar country-total data would 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 maps of national origin or global sources such as the FAO Soils Map of the World. Where possible, land areas associated with cropping systems (e.g. rotations and tillage practice), rather than simply area by crop, should be delineated and associated with the appropriate management factor values. [Note: This is applicable to the cropland biomass section as well since the methodology uses area-based estimates for specific crop types such as FAO classified "permanent crops".] Refer to Chapter 2 of this report.

National land-use and resource inventories, comprised of a collection of permanent sample points where data are collected at regular intervals, have some advantages over aggregate agricultural and land-use statistics. Inventory points can more readily be associated with a particular cropping system and the soil type associated with the particular location can be determined by sampling or by referencing the location to a suitable soil map. Inventory points 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 point-based resource inventory that includes cropland is the National Resource Inventory in the U.S. (Nusser and Goebel, 1997).

***Organic Soils***

The area of cultivated organic soils by climate regime (A) is required to estimate organic soil emissions. Similar databases and approaches as those outlined above can be used for deriving area estimates. An overlay of soils maps showing the spatial distribution of histosols (i.e. organic soils) with land use maps showing cropland area can provide initial information on areas with organic soils under agricultural use. In addition, because organic soils usually require extensive artificial drainage to be used for agricultural purposes, country-specific data on drainage projects combined with soil maps and surveys can be used to get a more refined estimate of relevant areas.

#### 3.3.1.2.1.4 Uncertainty Assessment

A formal assessment of uncertainty requires that uncertainty in per area emission/sequestration rates as well as uncertainty in the activity data (i.e. the land areas involved in land-use and management changes), and their interaction be estimated. Where available, estimates of the uncertainty of the revised global default values developed in this report are provided in the tables; these can be used with the appropriate estimates of variability in activity data to estimate uncertainty, using the guidance provided in Chapter 5 of this report. Inventory agencies should be aware that simple global defaults have a relatively high level of uncertainty associated with them when applied to specific countries. In addition, because the field studies available to derive the global defaults are not evenly distributed across climate regions, soil types and management systems, some areas – particularly in tropical regions – are underrepresented. For the Tier 2 methods, probability density functions (i.e. providing mean and variance estimates) can be derived for stock change factors, organic soil emission factors and reference C stocks as part of the process of deriving region- or country-specific data. For example, Ogle *et al.* (2003) applied linear mixed-effect models to derive probability density functions for US specific factor values and reference carbon stocks for agricultural soils. Activity data from a statistically-derived land use and management inventory system should provide a basis to assign estimates of uncertainty to areas associated with land-use and management 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 (Ogle *et al.*, 2003; Smith and Heath, 2001) – see Chapter 5 of this report.

## 3.3.1.3 NON-$CO_2$ GREENHOUSE GAS EMISSIONS

### NITROUS OXIDE

The *IPCC Guidelines* and *GPG2000* already address the following non-$CO_2$ emission sources:

- $N_2O$ emissions from application of mineral and organic fertilisers, organic residues and biological nitrogen fixation (*IPCC Guidelines*, Chapter 4 Agriculture);
- $N_2O$, $NO_x$, $CH_4$ and CO emissions from on-site and off-site biomass burning (*IPCC Guidelines*, Chapter 4 Agriculture); and
- $N_2O$ emissions from cultivation of organic soils.

It is *good practice* to follow the existing *IPCC Guidelines* and *GPG2000* and continue to report these emissions under the Agriculture sector.

### METHANE

Methane emissions from rice paddies are addressed in the *IPCC Guidelines* and *GPG2000* and should be reported under the Agriculture sector.

Changes in the rate of methane oxidation in aerobic soils are not addressed at this time. The limited current information indicates that the $CH_4$ sink is small as compared to the $CH_4$ sources from flooded soils such as rice paddies. As more research is done and additional information becomes available, a fuller consideration of the impact of various activities on methane oxidation should be possible.

## 3.3.2 Land Converted to Cropland

The conversion of land from other uses and from natural states to cropland will, in most cases, result in emissions of $CO_2$ from both biomass and soils, at least for some years following conversion, as well as $N_2O$ and $CH_4$ emissions from the soil. Possible exceptions are the irrigation of formerly arid lands, which can result in net carbon gains in soils and biomass, and conversion of degraded lands to cropland. The calculation of carbon emissions from conversion of forest land and grassland to cropland is found in the *IPCC Guidelines* in Section 5.2.3 (Forest and Grassland Conversion) and Section 5.3 ($CO_2$ Emissions and Uptake from Soils). When estimating emissions and removals from land-use conversions to cropland, it is *good practice* to consider three subcategories: change in carbon stocks in biomass (Section 3.3.2.1), change in carbon stocks in soil (Section 3.3.2.2), and emissions of nitrous oxide (Section 3.3.2.3). Methodological guidance is provided below for each of these subcategories.

It is *good practice* to estimate emissions/removals from 'land converted to cropland' using the methods described in this subsection for a period sufficient for the carbon stock changes to occur following land-use conversion. However, biomass and soil pools respond differently to land-use conversions and therefore, time periods are different for equilibrium carbon stocks to be reached. Changes in carbon in biomass pools are estimated using the method in Section 3.3.2.1 below for the first time period following the land-use conversion to cropland.[3] After this time period, countries should estimate carbon stock changes in biomass using methods described under Section 3.3.1.1 Cropland Remaining Cropland, Change in carbon stocks in biomass. Since the default inventory period for changes in soil carbon is 20 years, this period of time should be used in area accounting for conversions to cropland.

The summary equation for carbon stock change in Land Converted to Cropland is shown below in Equation 3.3.7. In addition, methodologies based on emissions coefficients are discussed for $N_2O$. Table 3.3.6 summarises the tiers for each of the carbon subcategories, as well as for the $N_2O$ subcategory.

**EQUATION 3.3.7**
**TOTAL CHANGE IN CARBON STOCKS IN LAND CONVERTED TO CROPLAND**

$$\Delta C_{LC} = \Delta C_{LC_{LB}} + \Delta C_{LC_{Soils}}$$

Where:

$\Delta C_{LC}$ = total change in carbon stocks in land converted to cropland, tonnes C $yr^{-1}$

$\Delta C_{LC_{LB}}$ = change in carbon stocks in living biomass in land converted to cropland, tonnes C $yr^{-1}$

$\Delta C_{LC_{Soils}}$ = change in carbon stocks in soil in land converted to cropland, tonnes C $yr^{-1}$

[3] The time period will depend on the frequency with which countries collect data. For example, if land use surveys are collected on a five-year cycle, e.g., 1990, 1995, 2000, then a land conversion that takes place in 1992 will be captured by the 1995 data collection and thus recorded using the methods below in the inventory report that employs survey data for 1995.

### 3.3.2.1 CHANGE IN CARBON STOCKS LIVING BIOMASS

This section provides *good practice guidance* 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 living 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, 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 3.3.1 Croplands remaining Croplands.

#### 3.3.2.1.1 METHODOLOGICAL ISSUES

The methodology estimates carbon stock change in living biomass. Currently, there is not sufficient information to provide a basic approach with default parameters to estimate carbon stock change in dead organic matter pools in land converted to cropland[4]. In addition, the methodology below considers carbon stock change in aboveground biomass only because limited data are available on belowground carbon stocks in perennial cropland.

**TABLE 3.3.6**
**TIER DESCRIPTIONS FOR SUBCATEGORIES UNDER LAND CONVERTED TO CROPLAND (LC)**

| Tier / Sub-categories | Tier 1 | Tier 2 | Tier 3 |
|---|---|---|---|
| Biomass | Use default coefficients to estimate carbon stock change in biomass resulting from land use conversions and for carbon in biomass that replaces cleared vegetation during the year of land use transition. | Use at least some country-specific carbon stock parameters to estimate carbon stock changes from land use conversion to cropland. Apportion carbon from biomass removal to burning, decay, and other nationally important conversion processes. Estimate non-$CO_2$ trace gas emissions from the portion of biomass burned both on-site and off-site. Use area estimates that are disaggregated to nationally relevant climate zones and other boundaries to match country-specific carbon stock parameters. | Use country-specific approach at fine spatial scale (e.g., modeling, measurement). |
| Carbon stocks in Soil | For change in soil carbon from mineral soils use default coefficients. The areas must be stratified by climate and soil type. For change in soil carbon from organic soils use default coefficients and stratify the areas by climatic region. For emissions from liming, use default emission factors. | For both mineral and organic soils use some combination of default and or country-specific coefficients and area estimates of increasingly finer spatial resolution. For emissions from liming, use emission factors differentiated by forms of lime. | Use country-specific approach at fine spatial scale (e.g., modeling, measurement) |
| Nitrous Oxide from soil oxidation during conversion | Use default parameters and coarse spatial disaggregation | Use of country-specific parameters and increased spatial disaggregation | Use country-specific approach at fine spatial scale (e.g., modeling, measurement) and report under LULUCF cropland remaining cropland |

[4] Any litter and dead wood pools (estimated using the methods described in Section 3.2.2.2) should be assumed oxidized following land conversion.

#### 3.3.2.1.1.1 Choice of Method

The *IPCC Guidelines* describe increasingly sophisticated alternatives that incorporate greater detail on the areas of land converted, carbon stocks on lands, and removal of carbon resulting from land conversions. *Good practice guidance* reflects this in a tiered methodology with the choice of tier depending on 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 subcategory of living biomass is considered significant based on principles outlined in Chapter 5. Countries should use the decision tree in Figure 3.1.2 to help with the choice of method.

**Tier 1:** The Tier 1 method follows the approach in *IPCC Guidelines* Section 5.2.3. Forest and Grassland Conversion where the amount of biomass that is cleared for cropland is estimated by multiplying the forest area converted in one year by the average carbon stock in biomass in the forest 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 each initial land use, including but not limited to forests.

Equation 3.3.8 summarises the major elements of a first order approximation of carbon stock change from land-use conversion to cropland. Average carbon stock change on a per area 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. As stated in the *IPCC Guidelines*, it is necessary to account for any vegetation that replaces the vegetation that was cleared during land use conversion. The *IPCC Guidelines* combine 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, $C_{After}$ and $\Delta C_{Growth}$ to increase transparency. At Tier 1, carbon stocks in biomass immediately after conversion ($C_{After}$) are assumed to be zero, i.e., the land is cleared of all vegetation before planting crops. Average carbon stock change per area 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 and change in biomass of perennial woody crops are counted following the methodology in Section 3.3.1.1 (Change in carbon stocks in biomass, in: Cropland Remaining Cropland).

The basic steps in estimating carbon stock change in biomass from land conversion to cropland are as follows:

(i) Estimate the average area of land undergoing a transition from non-cropland to cropland during a year ($A_{conversion}$), separately for each initial land use (i.e., forest land, grasslands, etc.) and final crop type (i.e., annual or perennial woody).

(ii) For each type of land use transition to cropland, use Equation 3.3.8 to estimate the resulting change in carbon stocks. Default data in Section 3.3.2.1.1.2 for $C_{After}$, $C_{Before}$, and $\Delta C_{Growth}$ can be used to estimate the total stock change on a per area basis for each type of land use transition. The estimate for stock change on a per area basis can then be multiplied by the appropriate area estimates from step 1.

(iii) Estimate the total carbon stock change from all land-use conversions to cropland by summing the individual estimates for each transition.

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

**EQUATION 3.3.8**
**ANNUAL CHANGE IN CARBON STOCKS IN LIVING BIOMASS IN LAND CONVERTED TO CROPLAND**

$$\Delta C_{LC_{LB}} = A_{Conversion} \bullet (L_{Conversion} + \Delta C_{Growth})$$

$$L_{Conversion} = C_{After} - C_{Before}$$

Where:

$\Delta C_{LC_{LB}}$ = annual change in carbon stocks in living biomass in land converted to cropland, tonnes C $yr^{-1}$

$A_{Conversion}$ = annual area of land converted to cropland, ha $yr^{-1}$

$L_{Conversion}$ = carbon stock change per area for that type of conversion when land is converted to cropland, tonnes C $ha^{-1}$

$\Delta C_{Growth}$ = changes in carbon stocks from one year of cropland growth, tonnes C $ha^{-1}$

$C_{After}$= carbon stocks in biomass immediately after conversion to cropland, tonnes C $ha^{-1}$

$C_{Before}$= carbon stocks in biomass immediately before conversion to cropland, tonnes C $ha^{-1}$

**Tier 2:** The Tier 2 calculations are structurally similar to Tier 1, with these distinctions. First, Tier 2 relies on at least some country-specific estimates of the carbon stocks in initial and final land uses rather than the defaults provided in Section 3.3.2.1.1.2. Area estimates for land converted to cropland are disaggregated 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. In addition, 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. The *IPCC Guidelines* Workbook provides step-by-step instructions for estimating carbon removals from burning and decay of biomass on-site and off-site and for estimating non-$CO_2$ trace gas emissions from burning (pages 5.7-5.17). Below is guidance on estimating carbon removals from burning and decay and Section 3.2.1.4 of this chapter provides further guidance on estimating non-$CO_2$ trace gas emissions from burning.

The basic equations for estimating the amount of carbon burned or left to decay are provided in Equations 3.3.10 and 3.3.11 below. This methodology addresses burning for the purposes of land clearing. Non-$CO_2$ emissions from burning for management of cropland remaining cropland are covered in the Agriculture chapter of *GPG2000*. The default assumption in Equations 3.3.10 and 3.3.11 is that only aboveground biomass, is burned or decays. Countries are encouraged to use additional information to assess this assumption, particularly for decaying belowground biomass. Equations 3.3.10 and 3.3.11 estimate the amount of carbon in biomass removed during a land use conversion to cropland that is burned (on-site and off-site) or that decays, respectively. The basic approach can be modified to address other conversion activities as well to meet the needs of national circumstances. Both equations use as an input the total amount of carbon in biomass removed during land clearing ($\Delta C_{conversion}$) (Equation 3.3.9), which is equivalent to area of land converted ($A_{Conversion}$) multiplied by the carbon stock change per area for that type of conversion ($L_{Conversion}$ in Equation 3.3.8).

The portion of biomass removed is sometimes used as wood products. In the case of wood products, countries may use the default assumption that carbon in wood products is oxidized in the year of removal. Alternatively, countries may refer to Appendix 3a.1 for estimation techniques for carbon storage in harvested wood products, which may be accounted for provided carbon in the product pool is increasing.

**EQUATION 3.3.9**

**CHANGE IN CARBON STOCKS AS A RESULT OF CLEARING BIOMASS IN A LAND USE CONVERSION**

$$\Delta C_{conversion} = A_{conversion} \bullet L_{conversion}$$

Where:

$\Delta C_{conversion}$ = change in carbon stocks as a result of clearing biomass in a land use conversion, tonnes C

$A_{Conversion}$ = area of land converted to croplands from some initial use, ha

$L_{Conversion}$ = carbon stocks removed when land is converted from some initial use to cropland, tonnes C $ha^{-1}$ (from Equation 3.3.8)

**EQUATION 3.3.10**

**CARBON LOSSES FROM BIOMASS BURNING, ON-SITE AND OFF-SITE**

$$L_{burn\ onsite} = \Delta C_{conversion} \bullet \rho_{burned\ on\ site} \bullet \rho_{oxid}$$

$$L_{burn\ offsite} = \Delta C_{conversion} \bullet \rho_{burned\ off\ site} \bullet \rho_{oxid}$$

Where:

$L_{burn}$ = carbon losses from biomass burned, tonnes C

$\Delta C_{conversion}$ = change in carbon stocks as a result of a clearing biomass in a land use conversion, tonnes C

$\rho_{burned\ on\ site}$ = fraction of biomass that is burned on-site, dimensionless

$\rho_{oxid}$ = fraction of biomass that oxidizes when burned, dimensionless

$\rho_{burned\ off\ site}$ = fraction of biomass that is burned off-site, dimensionless

**EQUATION 3.3.11**
**CARBON LOSSES FROM BIOMASS DECAY**

$$L_{decay} = \Delta C_{conversion} \bullet \rho_{decay}$$

$$\rho_{decay} = 1 - (\rho_{burned\ on\ site} + \rho_{burned\ off\ site})$$

Where:

$L_{decay}$ = carbon losses from biomass decay, tonnes C

$\Delta C_{conversion}$ = change in carbon stocks as a result of a clearing biomass in a land use conversion, tonnes C

$\rho_{decay}$ = fraction of biomass that is left on-site to decay, dimensionless

$\rho_{burned\ on\ site}$ = fraction of biomass that is burned on-site, dimensionless

$\rho_{burned\ off\ site}$ = fraction of biomass that is burned off-site, dimensionless

It is *good practice* for countries to use the terms $L_{burn\ on\ site}$ and $L_{burn\ off\ site}$ as inputs to estimate non-$CO_2$ trace gas emissions from burning following guidance provided in Section 3.2.1.4.

**Tier 3:** The Tier 3 method is similar to Tier 2, with the following distinctions: 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; carbon densities and soil carbon stock change are based on locally specific information, which makes possible a dynamic link between biomass and soil; and biomass volumes are based on actual inventories.

### 3.3.2.1.1.2 Choice of Emission/Removal Factors

**Tier 1:** Default parameters are provided in both the *IPCC Guidelines* and in this report to enable countries with limited data resources to estimate emissions and removals from this source. The first step in this methodology requires parameters for carbon stocks before conversion for each initial land use ($C_{Before}$) and after conversion ($C_{After}$). It is assumed that all biomass is cleared when preparing a site for cropland use, thus, the default for $C_{After}$ is 0 tonnes C $ha^{-1}$. Table 3.3.7 provides default carbon stock values for $C_{Before}$ in either forest or grassland land uses prior to clearing.

In addition, a value is needed for carbon stocks after one year of growth in crops planted after conversion ($\Delta C_{Growth}$). Table 3.3.8 provides defaults for $\Delta C_{Growth}$. Separate defaults are provided for annual non-woody crops and perennial woody crops. For lands planted in annual crops, the default value of $\Delta C_{Growth}$ 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 3.3.8). Default carbon stocks from one year of growth in perennial woody crops the same as those in Table 3.3.2. 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 provide 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 3.3.7**
**DEFAULT BIOMASS CARBON STOCKS REMOVED DUE TO LAND CONVERSION TO CROPLAND**

| Land-use category | Carbon stock in biomass before conversion ($C_{Before}$) (tonnes C $ha^{-1}$) | Error range # |
|---|---|---|
| Forest land | See Tables 3A.2 and 3A.3 in Annex 3A.1 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 3.2.2 (Land Converted to Forest land) |
| Grassland | See Table 3.4.2 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 3.3.8**
**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 ($\Delta C_{Growth}$) (tonnes C $ha^{-1}$) | Error range# |
|---|---|---|
| Annual cropland | 5 | ± 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- 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 burned on-site for both forest 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 burned on site are provided in Table 3A.13 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 burned 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 the rationale for the choice is documented. There is no default value for the amount of biomass taken off-site and burned; countries will need to develop a proportion based on national data sources. In Equation 3.3.10., the default proportion of biomass oxidized as a result of burning is 0.9, as originally stated in the *IPCC Guidelines.*

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: to report all emissions from decay in one year, recognizing that in reality they occur over a 10 year period, or report all emission from decay on an annual basis, estimating the rate as one tenth of the totals in Equation 3.3.11. If countries choose the latter option, they should add a multiplication factor of 0.10 to Equations 3.3.11.

**Tier 3:** Under Tier 3, all parameters should be country-defined using more accurate values rather than the defaults.

### 3.3.2.1.1.3 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 calculations on land converted to cropland. Higher tiers require greater specificity of areas. To be consistent with *IPCC Guidelines*, at a minimum, the area of forest 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 require expert judgment if Approach 1 in Chapter 2 is used for land area identification.

**Tier 1:** One type of activity data is needed for a Tier 1 approach: separate estimates of areas converted to cropland from initial land uses (i.e., forest land, grassland, settlement, etc.) to final crop type (i.e., annual or perennial) ($A_{conversion}$). 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. The methodology assumes that area estimates are based on a one-year time frame. If area estimates are assessed over longer time frames, they should be converted to average annual areas to match the default carbon stock values provided above. 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 Guidelines* 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:** Countries should strive 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 though 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 these 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).

#### 3.3.2.1.1.4. Uncertainty Assessment

**Tier 1:** The sources of uncertainty in this method are from the use of global or national average rates of conversion and coarse 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 corresponding 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 3.3.2.1.1.2 (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 +/- 75% of the carbon stock has been assumed based on expert judgement.

**Tier 2:** Actual area estimates for different land use transitions will enable more transparent accounting and allow experts to identify gaps and double counting of land areas. 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, which, together with uncertainty estimates on activity data derived using the advice in Chapter 2 should be used in the approaches to uncertainty analysis described in Chapter 5 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.

## 3.3.2.2 CHANGE IN CARBON STOCKS IN SOILS

### 3.3.2.2.1 METHODOLOGICAL ISSUES

Land conversion to cropland can occur from unmanaged land, including native, relatively undisturbed ecosystems (e.g. forest land, grassland, savanna, wetland) and from land managed for other uses (e.g. managed forest, managed grazing land). The more intensive management entailed in cropland use (i.e. high removal of harvested biomass, often frequent soil disturbance by tillage) will usually result in losses of C in soil organic matter and dead organic matter (surface litter and coarse woody debris). Any litter and dead wood pools (estimated using the methods described in Section 3.2.2.2) should be assumed oxidized following land conversion and changes in soil organic matter C stocks should be estimated as described below.

The total change in carbon stocks in soils on Lands Converted to Cropland is shown in Equation 3.3.12 below:

**EQUATION 3.3.12**
**ANNUAL CHANGE IN CARBON STOCKS IN SOILS IN LAND CONVERTED TO CROPLAND**

$$\Delta C_{LC_{Soils}} = \Delta C_{LC_{Mineral}} - \Delta C_{LC_{Organic}} - \Delta C_{LC_{Liming}}$$

Where:

$\Delta C_{LC_{Soils}}$ = annual change in carbon stocks in soils in land converted to cropland, tonnes C yr$^{-1}$

$\Delta C_{LC_{Mineral}}$ = change in carbon stocks in mineral soils in land converted to cropland, tonnes C yr$^{-1}$

$\Delta C_{LC_{Organic}}$ = annual C emissions from cultivated organic soils converted to cropland (estimated as net annual flux), tonnes C $yr^{-1}$

$\Delta C_{LC_{Liming}}$ = annual C emissions from agricultural lime application on land converted to cropland, tonnes C $yr^{-1}$

Criteria for selecting the most suitable estimation method are similar to that outlined for permanent cropland soils. Key factors include type of land conversion and the longevity of the conversion, and availability of suitable country-specific information to estimate reference soil C stocks and stock change and emission factors.

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 subcategory of soil organic matter is considered significant based on principles outlined in Chapter 5. Countries should use the decision tree in Figure 3.1.2 to help with the choice of method.

### 3.3.2.2.1.1 Choice of Method

#### *Mineral Soils*

The Tier 1 method is based on the *IPCC Guidelines* ($CO_2$ Emissions and Uptake by Soils from Land-Use and Management, Section 5.3), using Equation 3.3.3, following land conversion. Tier 1 methods rely on default values for reference C stocks and stock change factors and relatively aggregated data on the location and rates of land-use conversion.

For Tier 1, the initial (pre-conversion) soil C stock ($SOC_{(0-T)}$) is determined from the same reference soil C stocks ($SOC_{REF}$) used for all land uses (Table 3.3.3), together with stock change factors ($F_{LU}$, $F_{MG}$, $F_I$) appropriate for the previous land use as shown in Table 3.3.9 (also see Sections 3.2.1.3 (Forest soils) and 3.4.1.2 (Grassland soils)). For unmanaged land, as well as for managed forest and grazing land with low disturbance regimes, soil C stocks are assumed equal to the reference values (i.e. land use, management and input factors equal 1). Current ($SOC_0$) soil C stocks on land converted to cropland are estimated exactly as for permanent cropland, i.e., using the reference carbon stocks (Table 3.3.3) and stock change factors (Table 3.3.9). Thus, annual rates of emissions (source) or removals (sink) are calculated as the difference in stocks (over time) divided by the inventory time period (default is 20 years).

The calculation steps for determining $SOC_0$ and $SOC_{(0-T)}$ and net soil C stock change per ha of land area are as follows:

**Step 1:** Select the reference carbon stock value ($SOC_{REF}$), based on climate and soil type, for each area of land being inventoried.

**Step 2:** Calculate the pre-conversion C stock ($SOC_{(0-T)}$) of land being converted into cropland, based on the reference carbon stock and previous land use and management, which determine land use ($F_{LU}$), management ($F_{MG}$) and input ($F_I$ ) factors. Note that where the land being converted is forest or native grassland, the pre-conversion stocks will be equal to the native soil carbon reference stocks.

**Step 3:** Calculate $SOC_0$ by repeating step 2 using the same reference carbon stock ($SOC_{REF}$), but with land use, tillage and input factors that represent conditions in the land converted to cropland.

**Step 4:** Calculate the average annual change in soil C stock for the area over the inventory period ($\Delta C_{CC_{Mineral}}$ ).

**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 $ha^{-1}$ ● 0.58 ● 1 ● 0.91 = 36.9 tonnes C $ha^{-1}$. Thus the average annual change in soil C stock for the area over the inventory period is calculated as (36.9 tonnes C $ha^{-1}$ – 70 tonnes C $ha^{-1}$) / 20 yrs = -1.7 tonnes C $ha^{-1}$ $yr^{-1}$.

The *IPCC Guidelines* also provide estimates for C stock change associated with the transient land-use conversion to cropland represented by shifting cultivation. In this case, the stock change factors are different from those used if the conversion is to permanent cropland, and change in soil C stocks will depend on the length of the fallow (vegetation recovery) cycle. The soil carbon stocks calculated for shifting cultivation represent an average over the crop-fallow cycle. Mature fallow denotes situations where the non-cropland vegetation (e.g. forest, savanna) 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 factors representing shifting cultivation would provide the 'initial' C stocks in the calculations of changes following conversion.

The Tier 2 method for mineral soils also uses Equation 3.3.3, but involves country or region-specific reference C stocks and/or stock change factors and more disaggregated land use activity data.

### *Organic Soils*

Tier 1 and Tier 2 approaches for organic soils that are converted from other land uses to cropland within the inventory period are treated the same as long-term cropped organic soils, i.e., they have a constant emission factor applied to them, based on climate regime (see Equation 3.3.5 and Table 3.3.5). In Tier 2, emission factors are derived from country or region-specific data.

### *Mineral and organic soils*

For both mineral and organic soils, 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 for estimating soil C change from land-use conversions to cropland should employ models and data sets that are capable of representing transitions over time between different land use and vegetation types, including forest, savanna, grasslands, cropland. The Tier 3 method needs to 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 critical that models be validated with independent observations from country or region-specific field locations that are representative of the interactions of climate, soil and vegetation type on post-conversion change in soil C stocks.

### *Liming*

If agricultural lime is applied to cropland converted from other land uses then the methods for estimating $CO_2$ emissions from liming are the same as described for *Cropland Remaining Cropland*, in Section 3.3.1.2.1.1.

## 3.3.2.2.1.2 Choice of Emission/Removal Factors

### *Mineral soils*

The following variables are needed when using either the Tier 1 or Tier 2 method:

**Reference carbon stocks ($SOC_{REF}$)**

**Tier 1:** Under Tier 1, it is *good practice* to use the default reference carbon stocks ($SOC_{REF}$) provided in Table 3.3.3. These are updated from those provided in the *IPCC Guidelines* with the following improvements: i) estimates are statistically-derived from recent compilations of soil profiles under native vegetation, ii) 'Spodic' soils (defined as boreal and temperate zone podzols in WRB classification, Spodosols in USDA classification) are included as a separate category, iii) soils within the boreal climate region have been included.

**Tier 2:** For the Tier 2 method, reference soil C stocks can be determined from measurements of soils, for example, as part of a country's soil survey and mapping activities. It is important that reliable taxonomic descriptions of measured soils be used to group soils into the classes defined in Table 3.3.3 or if a finer subdivision of reference soil C stocks is used definitions of soil groupings need to be consistently and well documented. Advantages to using country-specific data for estimating reference soil C stocks include more accurate and representative values for an individual country and the ability to better estimate probability distribution functions that can be used in a formal uncertainty analysis.

**Stock change factors ($F_{LU}$, $F_{MG}$, $F_I$)**

**Tier 1:** Under Tier 1, it is *good practice* to use default stock change factors ($F_{LU}$, $F_{MG}$, $F_I$) provided in Table 3.3.9. These are updated from the *IPCC Guidelines*, based on a statistical analysis of published research. Definitions guiding the selection of appropriate factor values are provided in the table. Stock change factors are used in estimating both post- ($SOC_0$) and pre-conversion ($SOC_{(0-T)}$) stocks; values will vary according to land use and management conditions before and after the conversion. Note that where forest land or native grasslands are converted to cropland use, the stock change factors all have the value of one, such that the pre-conversion soil carbon stocks are equal to the native vegetation reference values ($SOC_{REF}$).

**Tier 2:** For the Tier 2 method, estimation of country-specific stock change factors for land-use conversion to cropland will typically be based on paired-plot comparisons representing converted and unconverted lands, where all factors other than land-use history are as similar as possible (e.g. Davidson and Ackermann, 1993). Ideally several sample locations can be found that represent a given land use at different times since conversion – referred to as a chronosequence (e.g. Neill *et al.*, 1997). There are few replicated long-term experiments of land- use conversions and thus stock change factors and emission factors for land-use conversions will have greater uncertainty than for permanent cropland. In evaluating existing studies or conducting new measurements it is critical that the plots being compared have similar pre-conversion histories and management as well as similar topographic position, soil physical properties and be located in close proximity. As for permanent cropland, required information includes C stock (i.e. mass per unit area to a specified depth) for each land use (and time point if a chronosequence). As previously described under *Cropland Remaining Cropland*, in the absence of specific information upon which to select an alternative depth interval, it is *good practice* to compare stock change factors at a depth of at least 30 cm (i.e. the depth used for Tier 1 calculations). Stock changes over a deeper depth may be desirable if a sufficient number of studies are available and if statistically significant differences in stocks due to land management are demonstrated at deeper depths. However, it is critical that the reference soil carbon stocks ($SOC_{Ref}$) and stock change factors ($F_{LU}$, $F_{MG}$, $F_I$) be determined to a common depth.

### *Organic soils*

**Tier 1** and **Tier 2** choice of C emission factors from organic soils recently converted to cropland should observe the same procedures for deriving emission factors as described earlier under the *Cropland Remaining Cropland* section.

**TABLE 3.3.9**
**RELATIVE SOIL STOCK CHANGE FACTORS ($F_{LU}$, $F_{MG}$, $F_I$) FOR LAND-USE CONVERSIONS TO CROPLAND**

| Factor value type | Level | Climate regime | *IPCC Guidelines* default | Error# | Definition |
|---|---|---|---|---|---|
| Land use | Native forest or grassland (non-degraded) | Temperate | 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 |
| | Shifting cultivation – Mature fallow | Tropical | 0.8 | ± 50% | |
| Land use, Management, & Input | Managed forest | See Equation 3.2.14 and accompanying text | | | |
| Land use, Management, & Input | Managed grassland | See default values in Table 3.4.5 | | | |
| Land use, Management, & Input | Cropland | See default values in Table 3.3.4 | | | |

# 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.

### 3.3.2.2.1.3 Choice of Activity Data

### *Mineral and Organic Soils*

At a minimum, countries should have estimates of the areas of land converted to cropland during the inventory period. If land use and management data are limited, aggregate data, such as FAO statistics on land conversions, can be used as a starting point, along with knowledge of country experts of the approximate distribution of land use types (e.g. forest land and grassland areas and their respective soil types) being converted and knowledge of the types of cropland practices being used on land converted to cropland. More detailed accounting 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, and/or hybrid inventory systems. Estimates of land-use conversions to cropland should be stratified according to major soil types, as defined for Tier 1, or based on country-specific stratifications if employed in Tier 2 or 3 approaches. This can be based on overlays with suitable soil maps and spatially-explicit data of the location of land conversions.

### 3.3.2.2.1.4 Uncertainty Assessment

Because most conversions to cropland uses entail losses from soil carbon stocks, the most critical data from the standpoint of reducing overall uncertainty is accurate estimates of the land area being converted to cropland. Due to their high native soil carbon stocks and potential for large losses, conversions to cropland occurring on organic soils, as well as wetland mineral soils and volcanic soils, are of particular importance. Reducing uncertainty in the estimates of stock change and emission factors for lands recently (<20 yrs) converted to cropland can best be accomplished from direct monitoring of C stocks (and emissions) before and after (for a period of several year) conversion to cropland, at the same location. However, data based on indirect estimates, so-called chronosequences, in which land converted to cropland at different times in the past and at different locations, are more common. Use of estimates based on chronosequences will have a higher uncertainty than direct monitoring over time. In constructing and evaluating chronosequences it is important to select areas which are as similar as possible with respect to original vegetation, soil type and landscape position – i.e. the main difference being time since conversion. Estimates should be based on more than one chronosequence. Overall uncertainty assessment will require combining uncertainties associated with stock change and emission factors and activity data concerning land areas converted to cropland.

## 3.3.2.3 NON-$CO_2$ GREENHOUSE GAS EMISSIONS

This section deals with the increase in $N_2O$ emissions arising from the conversion of forest land, grassland, and other land to cropland. An increase in $N_2O$ emissions can be expected following the conversion of forest land, grassland and other land to cropland. This is a consequence of the enhanced mineralisation (conversion to inorganic form) of soil organic matter (SOM) that normally takes place as a result of that conversion. The mineralisation results not only in a net loss of soil C and hence a net $CO_2$ emission (Section 3.3.2.2.1.2) but also in associated conversion of nitrogen previously in the SOM to ammonium and nitrate. Microbial activity in the soil converts some of the ammonium and nitrate present to $N_2O$. Thus an increase in this microbial substrate caused by a net decrease in SOM can be expected to give an increase in net $N_2O$ emissions. The approach here is to use the same emission factor ($EF_1$) as that used for direct emissions from agricultural land which has been in cultivation for a long time (see Agriculture, *GPG2000*), and has the same logical basis, i.e. that N converted into inorganic form in the soil, as a result of mineralisation, is all of equal value as a substrate for the organisms producing $N_2O$ by nitrification and denitrification, no matter what the organic source is, soil organic matter in this case of land-use conversion to cropland, or plant roots and crop residues from cultivation after harvest, or added organic manures as in the case of the $N_2O$ emissions addressed in the *IPCC Guidelines*, Chapter 4 Agriculture and *GPG2000*.

Guidance on estimating trace gas emissions ($N_2O$, $NO_x$, $CH_4$ and CO) from on-site and off-site biomass burning is provided in Section 3.2.1.4.

The rate of methane oxidation in aerated topsoils can change due to conversion to cropland. The reduction in oxidation is not addressed in this report, however, due to limited information. In the future, as more data become available, it may be possible to provide a fuller consideration of the impact of various activities on methane oxidation rates.

### 3.3.2.3.1 METHODOLOGICAL ISSUES

### NITROUS OXIDE FROM MINERAL SOILS

#### 3.3.2.3.1.1 Choice of Method

The total emissions of $N_2O$ are equivalent to the sum of all $N_2O$ emissions from land use conversions as shown in Equation 3.3.13 and 3.3.14. These are emissions from mineralisation of soil organic matter resulting from conversion of forest land, grassland, settlements or other land to cropland.

**EQUATION 3.3.13**
**TOTAL ANNUAL EMISSIONS OF $N_2O$ FROM MINERAL SOILS IN LAND CONVERTED TO CROPLAND**

$$\text{Total } N_2O\text{-}N_{conv} = \sum_i N_2O\text{-}N_{conv,i}$$

Where:

Total $N_2O$-$N_{conv}$ = total annual emissions of $N_2O$ from mineral soils in land converted to cropland, kg $N_2O$-N $yr^{-1}$

$N_2O$-$N_{conv,i}$ = $N_2O$ emissions from land conversion type *i*, kg $N_2O$-N $yr^{-1}$

Emissions from fertilisation: $N_2O$ emissions from nitrogen application in the preceding land use (managed forest or grassland) and new land use (cropland) are calculated elsewhere in the inventory (GPG 2000) and should not be reported here, to avoid double counting.

**EQUATION 3.3.14**
**$N_2O$ EMISSIONS AS A RESULT OF THE DISTURBANCE ASSOCIATED WITH LAND-USE CONVERSION OF FOREST LAND, GRASSLAND, OR OTHER LAND TO CROPLAND**

$$N_2O\text{-}N_{conv} = N_2O_{net\text{-}min}\text{-}N$$

$$N_2O_{net\text{-}min}\text{-}N = EF_1 \bullet N_{net\text{-}min}$$

Where:

$N_2O\text{-}N_{conv}$ = $N_2O$ emissions as a result of the disturbance associated with land-use conversion of forest land, grassland, or other land to cropland, kg $N_2O$-N $yr^{-1}$

$N_2O_{net\text{-}min}$-N = additional emissions arising from the land-use change, kg $N_2O$-N $yr^{-1}$

$N_{net\text{-}min}$ = N released annually by net soil organic matter mineralisation as a result of the disturbance, kg N $yr^{-1}$

$EF_1$ = IPCC default emission factor used to calculate emissions from agricultural land caused by added N, whether in the form of mineral fertilisers, manures, or crop residues, kg $N_2O$-N/kg N. (The default value is 0.0125 kg $N_2O$-N/kg N)

Note: Multiply $N_2O\text{-}N_{conv}$ by 44/28 and$10^{-6}$ to obtain $N_2O$ emissions in Gg $N_2O$ $yr^{-1}$

The N released by net mineralisation, $N_{net\text{-}min}$, can be calculated following the calculation of the soil C mineralised over the same period (20 years). The default method assumes a constant C:N ratio in the soil organic matter over the period, thus:

**EQUATION 3.3.15**
**ANNUAL NITROGEN RELEASED BY NET SOIL ORGANIC MINERALISATION AS A RESULT OF THE DISTURBANCE (BASED ON SOIL C MINERALISED)**

$$N_{net\text{-}min} = \Delta C_{LC_{Mineral}} \bullet 1 / \text{C:N ratio}$$

Where:

$N_{net\text{-}min}$ = annual N released by net soil organic matter mineralisation as a result of the disturbance, kg N $yr^{-1}$

$\Delta C_{LC_{Mineral}}$ = values obtained from Equation 3.3.12 (see also Section 3.3.2.2.1.1)), where applied to an area of land converted to cropland (see Section 3.3.2.2.1.), kg C $yr^{-1}$

C:N ratio = the ratio by mass of C to N in the soil organic matter (SOM), kg C $(kg\ N)^{-1}$

**Tier 1:** Use default values and minimal spatial disaggregation with Equations 3.3.13 and 3.3.14

**Tier 2:** Actual measurements of locally specific C:N ratios in SOM will improve the calculations of $N_2O$ emissions after conversion.

**Tier 3:** Tier 3 comprises a more dynamic way of simulating emissions using process models, based on locally specific data, possibly spatially explicit, taking into account local characteristics of the land use conversion to cropland.

### 3.3.2.3.1.2 Choice of Emission Factor

The following factors are needed:

- **$EF_1$:** The emission factor for calculating emissions of $N_2O$ from N in the soil. The global default value is 0.0125 kg $N_2O$-N/kg N, based on the general default emission factor used for $N_2O$ emissions in Chapter 4 (Agriculture) of the *IPCC Guidelines*.
- **C released** is calculated using Equation 3.3.3.
- **C:N ratio:** The ratio of C to N in soil organic matter is by default 15. This reflects the somewhat greater C:N ratio found in forest or grassland soils compared to most cropland soils where C:N ratios typically around 8-12.

The box below highlights ways in which further refinement of emissions estimates may be made, by analogy with the equivalent text in *GPG2000*.

**BOX 3.3.1**
***GOOD PRACTICE* IN DERIVATION OF COUNTRY-SPECIFIC EMISSION FACTORS**

In situations where higher-tier methods may be possible, the following points apply:

*Good practice* requires the measurement of $N_2O$ emissions by individual sub-source category (e.g. synthetic fertiliser ($F_{SN}$), animal manure ($F_{AM}$), crop residue mineralisation ($F_{CR}$) and (in the present context of land-use conversion to cropland), mineralisation of soil organic N ($F_{OM\text{-}min}$).

For $N_2O$ emission factors to be representative of environmental and management conditions within the country, measurements should be made in the major crop growing regions within a country, in all seasons, and if relevant, in different geographic and soil regions and under different management regimes. Soil factors such as texture and drainage condition, temperature and moisture will affect EFs (Firestone and Davidson, 1989; Dobbie *et al.*, 1999).

Validated, calibrated, and well-documented simulation models may be a useful tool to develop area-average $N_2O$ emission factors on the basis of measurement data.

Regarding measurement period and frequency, $N_2O$ emission measurements should be taken over an entire year (including fallow periods), and preferably over a series of years, in order to reflect differences in weather conditions and inter-annual climatic variability. Measurements should be frequent during the initial period after land conversion.

#### 3.3.2.3.1.3 Choice of Activity Data

**$A_{conv}$**: The area of land being converted is required. For Tier 1 the $A_{conv}$ is a single value, but for Tier 2 it is disaggregated by the types of conversions.

## 3.3.3 Completeness

A complete data series for land area estimates contains, at a minimum, the area of land within country boundaries that is considered cropland during the time period covered by land use surveys or other data sources and for which greenhouse gas emission and removals are estimated in the LULUCF sector. The total area covered by the cropland inventory methodology is the sum of land remaining in cropland and land converted to cropland during the time period. This inventory methodology may not include some cropland areas where 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. Therefore, it is possible for the total cropland area for which estimates are prepared to be less than the total area of cropland within country boundaries. In this case, it is *good practice* for countries to document and explain the difference in cropland area in the inventory and total cropland within their boundaries. Countries are encouraged to track through time the total area of land in cropland within country boundaries, keeping transparent records on which portions are used to estimate carbon dioxide emissions and removals. As addressed in Chapter 2, all cropland areas, including those not covered by the emissions inventory, should be part of the consistency checks to help avoid double counting or omission. When summed with area estimates for other land uses, the cropland area data series will enable a complete assessment of the land base included in a countries' LULUCF sector inventory report.

Countries that use Tier 2 or 3 methods for cropland biomass and soil pools should include more detail in their inventory on the cropland area data series. For example, countries may need to stratify the cropland area by major climate and soil types, including both the inventoried and non-inventoried cropland areas. When stratified land areas are used in the inventory, it is *good practice* for countries to use the same area classifications for both the biomass and soils pools. 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.

## 3.3.4 Developing a Consistent Time Series

To maintain a consistent time series, it is *good practice* for countries to maintain records on the cropland areas used in inventory reports over time. These records should track the total cropland area included in the inventory, subdivided by land remaining in cropland and land converted to cropland. Countries are encouraged to include an estimate of the total cropland area within country boundaries. To ensure that area estimates are treated consistently through time, land use definitions should be clearly defined and kept constant. If changes are made to land use definitions, it is *good practice* to keep transparent records of how the definition changed. Consistent definitions should also be used for each of the cropland types and management systems included in the inventory. In addition, to facilitate the proper accounting of carbon emissions and removals over several periods, information on historic land conversions can be utilized. Even if a country cannot rely on historic data for current inventories, improvements to current inventory practices to provide the ability to track land conversions across time will have benefits in future inventories.

## 3.3.5 Reporting and Documentation

The categories described in Section 3.3 can be reported using the reporting tables in Annex 3A.2. The estimates under the cropland category can be compared with the reporting categories in the *IPCC Guidelines* as follows:

- Carbon dioxide emissions and removals in biomass in cropland remaining cropland to IPCC Reporting Category 5A, Changes in woody biomass;
- Carbon dioxide emissions and removals in soils in cropland remaining cropland to IPCC Reporting Category 5D, Changes in soil carbon; and
- Carbon dioxide emissions and removals resulting from land-use conversions to cropland to IPCC Reporting Category 5B for biomass, IPCC Reporting category 5D for soils, and IPCC Reporting Category 5E for non-$CO_2$ gases.

It is *good practice* to maintain and archive all information used to produce national inventory estimates. Metadata and data sources for information used to estimate country-specific factors should be documented and both mean and variance estimates provided. Actual databases and procedures used to process the data (e.g. statistical programs) to estimate country-specific factors should be archived. Activity data and definitions used to categorise or aggregate the activity data must be documented and archived. Procedures used to categorise activity data by climate and soil types (for Tier 1 and Tier 2) must be clearly documented. For Tier 3 approaches that use modelling, model version and identification must be documented. Use of dynamic models requires that copies of all model input files as well as copies of model source code and executable programs be permanently archived.

## 3.3.6 Inventory Quality Assurance/Quality Control (QA/QC)

It is *good practice* to implement quality control checks and external expert review of inventory estimates and data. Specific attention should be paid to country-specific estimates of stock change and emission factors to ensure that they are based on high quality data and verifiable expert opinion.

Specific QA/QC checks across the cropland methodology include:

Cropland remaining cropland: Cropland soil estimates may be based on area data that includes both perennial woody crops and annual crops, while biomass estimates are based on area data for perennial woody crops only. Therefore, the area estimates underlying biomass and soils estimates in cropland remaining cropland may differ, with biomass estimates based on a smaller land area than soil estimates. This will be true in most cases, except in countries where cropland is comprised entirely of perennial woody crops or management and land use is constant on annual crops.

Lands converted to cropland: Aggregate area totals for land converted to cropland should be the same in the biomass and soils estimations. While biomass and soil pools may be disaggregated to different levels of detail, the same general categories should be used to disaggregate the area data.

For all soil carbon stock change estimates using Tier 1 or Tier 2 methods, total areas for each climate-soil type combination must be the same for the start (year$_{(0-T)}$) and the end (year$_{(0)}$) of the inventory period (see Equation 3.3.4).

## 3.3.7 Estimation of Revised GPG Tier 1 Defaults for Mineral Soil C Emissions/Removals for Cropland (see Table 3.3.4)

Cropland management factors were computed for tillage, input, set-aside, and land use conversion from grassland or forest land. The land use conversion factor represents the loss of carbon that occurs after 20 years of continuous cultivation. Tillage factors represent the impact of changing management from a conventional tillage system, in which the soil is completely inverted, to conservation practices, including no-till and reduced till. No-tillage is direct seeding without tillage of the soil. Reduced tillage involves some tillage, but does not involve full inversion of the soil and typically leaves more than 60% of the soil surface covered by residue, including practices such as chisel, mulch, and ridge tillage. The input factors represent the effect changing carbon input to the soil by planting more productive crops, cropping intensification, or applying amendments; input factors include cropping systems categorised as low, medium, high, and high w/manure amendments. Low input factors represent low residue crops, rotations with bare-fallow, or cropping systems in which the residue is burned or removed from the field. Medium input cropping systems represent cereals in which the residue is returned to the field or rotations receiving organic amendments that otherwise would be considered low input due to residue removal. High input rotations have high residue-yielding crops, cover crops, improved vegetated fallow, or years with grass cover, such as hay or pasture in the rotation. Tillage and input factors represent the effect on C stocks after 20 years since the management change. Set-aside factors represent the effect of temporary removal of cropland from production and placing it into grass vegetation for a period of time that may extend to 20 years.

The data were synthesized 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 interdependence in times series data and the interdependence among data points representing different depths from the same study. 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 conversion factor, which represents the average loss of carbon at 20 years or longer time period following cultivation. Users of this carbon accounting method can approximate the annual change in carbon storage by the dividing the inventory estimate by 20. Variance was calculated for each of the factor values, and can be used to construct probability distribution functions with a normal density.

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