CHAPTER 5

CROPLAND

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5.1 INTRODUCTION

No refinement.

5.2 CROPLAND REMAINING CROPLAND

No refinement.

5.2.1 Biomass

5.2.1.1 CHOICE OF METHODS

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

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

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

Tier 1

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

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

Under Tier 1, updated default factors shown in updated Table 5.1, Table 5.2 and Table 5.3, are applied to nationally derived estimates of land areas. For perennial cropland C uptake, multiply unharvested area that is still younger than the age of maturity by the above-ground growth rate. If harvest and immature areas are unknown, it is assumed that in cropland remaining cropland, the annual harvest area is equal to total area divided by rotation length in years. For perennial cropland C losses, the updated tables provide two types of carbon stocks of perennial woody biomass per area. One is maximum carbon stock at harvest/maturity state (L_{max}). This is appropriate for estimating harvest loss due to crop renewal. The other is the mean carbon stock over the whole lifetime of the crop (L_{mean}). This is used for loss due to conversion to another land use where the age of converted cropland is unknown. These values should be used appropriately to calculate carbon losses following the guidance in 5.2.1.2.

Tier 2

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

A Tier 2 estimate, in contrast, will generally develop estimates for the major woody crop types by climate zones, using country-specific carbon accumulation rates and stock losses where possible or country-specific estimates of carbon stocks at two points in time. Under Tier 2, carbon stock changes are estimated for above-ground and below-ground biomass in perennial woody vegetation. Tier 2 methods involve country-specific or region-specific estimates of biomass stocks by major cropland types and management system and estimates of stock change as a function of major management system (e.g., dominant crop, productivity management). To the extent possible, it is *good practice* for countries to incorporate changes in perennial crop or tree biomass using country-specific or region-specific data. Where data are missing, default data may be used.

Tier 3

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

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

5.2.1.2 CHOICE OF EMISSION FACTORS

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

Above-ground woody biomass growth rate

Tier 1

Updated Tables 5.1 to 5.3 provide estimates of biomass stocks and/or biomass growth rates and losses for major climatic regions and agricultural systems. Updated Table 5.1 provides default values of biomass growth and losses applicable to agroforestry cropping systems in broad climate regions. Agroforestry systems are defined in Table 5.5. Updated Table 5.2 provides default sequestration rates in above- and below-ground biomass for agro-forestry systems by region and climate zone. Updated Table 5.3 provides default values of biomass growth and losses for perennial cropping monoculture systems. Countries should use appropriate default values of above-ground biomass growth rate relative to each climate region and cropping system from updated Table 5.1, Table 5.2 or Table 5.3. However, given the large variation in cropping systems, incorporating trees or tree crops, it is *good practice* to seek national data on above-ground woody biomass growth rate.

Tier 2

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

TABLE 5.1 (UPDATED[1])
DEFAULT COEFFICIENTS FOR ABOVE-GROUND BIOMASS AND HARVEST/MATURITY CYCLES IN AGROFORESTRY SYSTEMS CONTAINING PERENNIAL SPECIES[2]

Climate Region	Agroforestry system[3]	N	Tree density (Stems ha^{-1})	Maximum above-ground biomass carbon stock at harvest ***L_{max} (tonnes C ha^{-1})	Harvest /Maturity cycle** (yr)	Biomass accumulation rate (G)* (tonnes C ha^{-1} yr^{-1})	Mean biomass carbon loss *** (L_{mean}) (tonnes C ha^{-1} yr^{-1})
Tropical	Fallow	69	6074	22.1 ± 52%	5 ± 50%	4.42 ± 15%	11.1 ± 26%
	Hedgerow[4]	3	1481	9.4 ± 59%	20 ± 50%	0.47 ± 31%	4.7 ± 29%
	Alley cropping	90	8568	47.4 ± 52%	20 ± 50%	2.37 ± 13%	23.7 ± 26%
	Multistrata	51	929	65.0 ± 54%	20 ± 50%	3.25 ± 21%	32.5 ± 27%
	Parkland	7	152	11.8 ± 76%	20 ± 50%	0.59 ± 58%	5.9 ± 38%
	Shaded Perennial	28	4236	48.0 ± 55%	20 ± 50%	2.4 ± 24%	24.0 ± 28%
	Silvoarable	22	880	72.2 ± 60%	20 ± 50%	3.61± 33%	36.1 ± 30%
	Silvopasture	18	1609	58.2 ± 80%	20 ± 50%	2.91 ± 63%	29.1 ± 40%
Temperate	Hedgerow[4]	12	816	26.1 ± 59%	30 ± 33%	0.87 ± 49%	13.1 ± 29%
	Silvoarable	14	202	27.3 ± 62%	30 ± 33%	0.91 ± 52%	13.7 ± 31%
	Silvopasture	10	854	69.9 ± 61%	30 ± 33%	2.33 ± 52%	35.0 ± 31%

*Source: biomass carbon accumulation rate, G, from Cardinael *et al* (2018). Uncertainty = 95% CI.

** Harvest/Maturity cycle and uncertainty are nominal estimates.

*** calculated (L_{max} = G * Maturity cycle; Lmean = L_{max}/2)

[1] Replaces Table 5.1 from the *2006 IPCC Guidelines*

[2] See Table 5.3 for monocultures

[3] See Table 5.4 for agroforestry system definitions

[4] Biomass storage rates and tree density for hedgerows are presented per kilometer of hedgerows, not per hectare of agricultural field or per hectare of hedgerow

Tier 3

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

TABLE 5.2 (UPDATED[1])
DEFAULT COEFFICIENTS FOR ABOVE- AND BELOW-GROUND BIOMASS IN AGROFORESTRY SYSTEMS CONTAINING PERENNIAL SPECIES[2]

Climate Region	Region	Agroforestry system	N *	Tree density (stems ha^{-1})	Above-ground biomass accumulation rate (G) (tonnes C ha^{-1} yr^{-1})	Below-ground biomass accumulation rate (tonnes C ha^{-1} yr^{-1})
Cool Temperate	Asia	Silvoarable	2	833	2.97 ± 75%	0.77
	Europe	Silvopasture	4	225	2.17 ± 47%	0.56
	North America	Hedgerow[3]	12	816	0.87 ± 49%	0.23
		Silvoarable	7	111	0.59 ± 29%	0.14
		Silvopasture	1	571	0.97 ± 75%	0.11
	South America	Silvopasture	1	400	1.18 ± 75%	0.52
	All regions	Hedgerow[3]	12	816	0.87 ± 49%	0.23
		Silvoarable	9	271	1.12 ± 62%	0.28
		Silvopasture	6	312	1.81 ± 44%	0.48
Warm Temperate	Europe	Silvoarable	5	76	0.52 ± 102%	0.14
		Silvopasture	4	1667	3.11 ± 91%	1.03
Temperate (ALL)	All Regions	Hedgerow[3]	12	816	0.87 ± 49%	0.23
		Silvoarable	14	202	0.91 ± 54%	0.23
		Silvopasture	10	854	2.33 ± 52%	0.70
Tropical Dry	Africa	Fallow	22	-	5.61 ± 21%	2.54
		Hedgerow[3]	2	1667	0.48 ± 75%	0.12
		Alley cropping	20	1000	1.88 ± 28%	0.45
		Multistrata	3	2771	1.63 ± 26%	0.46
		Parkland	7	152	0.59 ± 58%	0.21
	Asia	Fallow	9	1250	5.61 ± 59%	0.53
		Alley cropping	15	10430	2.79 ± 24%	0.67
		Silvoarable	6	540	6.24 ± 36%	1.62
		Silvopasture	17	1609	3.07 ± 62%%	0.84
	All Regions	Fallow	31	1250	5.61 ± 22%	1.95
		Hedgerow[3]	2	1667	0.48 ± 75%	0.12
		Alley cropping	35	5041	2.27 ± 19%	0.54
		Multistrata	3	2771	1.63 ± 26%	0.46
		Parkland	7	152	0.59 ± 58%	0.21
		Silvoarable	6	540	6.24 ± 36%	1.62
		Silvopasture	17	1609	3.07 ± 62%	0.84
Tropical Moist	Africa	Alley cropping	28	7233	2.75 ± 22%	0.59
		Multistrata	3	1902	2.98 ± 28%	0.72
		Shaded Perennial	5	-	1.82 ± 34%	0.44
		Silvoarable	5	-	5.09 ± 39%	1.22

TABLE 5.2 (UPDATED) (CONTINUED)
DEFAULT COEFFICIENTS FOR ABOVE- AND BELOW-GROUND BIOMASS IN AGROFORESTRY SYSTEMS CONTAINING PERENNIAL SPECIES[2]

Climate Region	Region	Agroforestry system	N	Tree density (stems ha^{-1})	Above-ground biomass accumulation rate (G) (tonnes C ha^{-1} yr^{-1})	Below-ground biomass accumulation rate (tonnes C ha^{-1} yr^{-1})
Tropical Moist	Asia	Fallow	1	-	5.30 ± 75%	1.27
		Multistrata	21	628	3.03 ± 30%	0.73
		Shaded Perennial	2	1481	2.07 ± 36%	0.50
		Silvoarable	11	1065	1.5 ± 44%	0.35
	Central America	Alley cropping	15	25000	2.28 ± 23%	0.55
	South America	Shaded Perennial	6	4131	3.06 ± 66%	0.71
	All Regions	Fallow	1	-	5.30 ± 75%	1.27
		Alley cropping	43	13733	2.59 ± 17%	0.58
		Multistrata	24	802	3.02 ± 26%	0.73
		Shaded Perennial	13	3071	2.43 ± 40%	0.57
		Silvoarable	16	1065	2.63 ± 42%	0.62
Tropical montane	Africa	Fallow	30	7521	3.12 ± 15%	1.12
Tropical Wet	Africa	Fallow	3	-	6.21 ± 53%	1.49
		Multistrata	2	-	2.89 ± 75%	0.69
		Shaded Perennial	1	1477	3.16 ± 75%	0.71
	Asia	Fallow	2	-	2.00 ± 75%	0.48
		Multistrata	11	-	4.83 ± 50%%	1.16
		Shaded Perennial	2	1608	1.79 ± 75%	0.42
		Silvopasture	1	-	0.06 ± 75%	0.01
	Central America	Hedgerow[3]	1	1110	0.43 ± 75%	0.10
		Alley cropping	12	1203	1.88 ± 51%	0.45
		Multistrata	1	-	3.25 ± 75%	0.78
		Shaded Perennial	10	5967	2.28 ± 42%	0.51
	South America	Fallow	2	-	4.76 ± 75%	1.14
		Multistrata	10	475	2.6 ± 42%	0.70
		Shaded Perennial	2	-	2.96 ± 75%	0.71
	All Regions	Fallow	7	-	4.59 ± 45%	1.10
		Hedgerow[3]	1	1110	0.43 ± 75%	0.10
		Alley cropping	12	1203	1.88 ± 51%	0.45
		Multistrata	24	475	3.25 ± 31%	0.91
		Shaded Perennial	15	4766	2.36 ± 29%	0.54
		Silvopasture	1	-	0.06 ± 75%	0.01

TABLE 5.2 (UPDATED) (CONTINUED)
DEFAULT COEFFICIENTS FOR ABOVE- AND BELOW-GROUND BIOMASS IN AGROFORESTRY SYSTEMS CONTAINING PERENNIAL SPECIES[2]

Climate Region	Region	Agroforestry system	N	Tree density (stems ha^{-1})	Above-ground biomass accumulation rate (G) (tonnes C ha^{-1} yr^{-1})	Below-ground biomass accumulation rate (tonnes C ha^{-1} yr^{-1})
Tropical All	All Regions	Fallow	69	6074	4.42 ± 15%	1.49
		Hedgerow[3]	3	1481	0.47 ± 31%	0.11
		Alley cropping	90	8568	2.37 ± 13%	0.55
		Multistrata	51	929	3.25 ± 21%	0.80
		Parkland	7	152	0.59 ± 58%	0.21
		Shaded Perennial	28	4236	2.40 ± 24%	0.55
		Silvoarable	22	880	3.61 ± 33%	0.89
		Silvopasture	18	1609	2.91 ± 63%	0.79

Source: Cardinael *et al* (2018).

[1] Replaces Tables 5.2 and 5.3 from the *2006 IPCC Guidelines*

[2] See Table 5.3 for monocultures.

[4] Biomass storage rates and tree density for hedgerows are presented per kilometer of hedgerows, not per hectare of agricultural field or per hectare of hedgerow

* Where N < 3 a nominal uncertainty estimate of ± 75% is given.

TABLE 5.3 (UPDATED[1])
DEFAULT MAXIMUM AND TIME-AVERAGED MEAN ABOVE-GROUND BIOMASS AND ABOVE GROUND BIOMASS ACCUMULATION RATE FOR PERENNIAL CROPLAND MONOCULTURES (TONNES HA^{-1})

Domain	Cropping system	Maximum above-ground biomass carbon stock at harvest (L_{max}) (tonnes C ha^{-1})	Harvest /Maturity cycle (yr)	Above-ground biomass accumulation rate (G) (tonnes C ha^{-1} yr^{-1})	Mean biomass carbon stock (L_{mean}) (tonnes C ha^{-1})	References
Temperate	Olive	9.1 ± 15%	20 ± 23%	0.46 ± 27%	6.9 ± 25%	[1]
	Orchard e.g. apple	8.5 ± 19%	20 ± 42%	0.43 ± 46%	6.4 ± 25%	[1]
	Vine e.g. grape	5.5 ± 18%	20 ± 18%	0.28 ± 26%	2.8 ± 25%	[1]
	Short Rotation Coppice	12.69 ± 40%	4	3.2 ± 40%	6.35 ± 40%	[2] + adjust-ment from [3]
Tropical	Oil palm *Elaeis guineensis*	60.0 ± 41%	25	2.4 ± 41%	30.0 ± 41%	[4]
	Rubber *Hevea brasiliensis*	80.2 ± 15%	27	3.0 ± 13%	40.1 ± 15%	[5]
All	Tea *Camelia sinensis*	20.7 ± 50%	30	0.7 ± 25%	18.3 ± 25%	[6]

[1] Canaveira, P. et al 2018.
[2] Hauk S, Knoke T, Wittkopf S 2013
[3] Krasuska E, Rosenqvist H. 2012
[4] Chave, J. 2015
[5] Blagodatsky, S., Xu, J., Cadisch, G. 2016
[6] Zhang M, et al. 2017
[1] Updated Table 5.3 from *2006 IPCC Guidelines*

Below-ground biomass accumulation

Tier 1

The default assumption is that there is no change in below-ground biomass of perennial trees in agricultural systems. There are limited below-ground biomass data for agricultural systems.

Tier 2

This includes the use of actually measured below-ground biomass data from perennial woody vegetation. Estimating below-ground biomass accumulation is recommended for Tier 2 calculation. Estimates are provided in Table 5.2. Root-to-shoot ratios show wide ranges in values at both individual species (e.g., Anderson *et al.*, 1972*)* and community scales (e.g., Jackson *et al.*, 1996; Cairns *et al.*, 1997*)*. Limited data is available for below ground biomass thus, as far as possible, empirically-derived root-to-shoot ratios specific to a region or vegetation type should be used.

Tier 3

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

Biomass losses from removal, fuelwood and disturbance

Tier 1

The default assumption is that all biomass lost is assumed to be emitted in the same year. Limited biomass removal, fuelwood gathering and disturbance loss data from cropland source are available. Food and Agriculture Organization of the United Nations (FAO) provides total roundwood and fuelwood consumption data, but not separated by source (e.g., Cropland, Forest Land, etc.). It is recognized that statistics on fuelwood are extremely poor and uncertain worldwide. Default removal and fuelwood gathering statistics (discussed in Chapter 4, Section 4.2) may include biomass coming from cropland such as when firewood is harvested from home gardens. Thus, it is necessary to ensure no double counting of losses occurs. If no data are available for roundwood or fuelwood sources from Cropland, the default approach will include losses in Forest Land (Section 4.2) and will exclude losses from Cropland. Updated Tables 5.1 and 5.3 provide default values of maximum carbon stock per area (L_{max}) and mean carbon stock per area (L_{mean}). Countries should use L_{max} in updated Table 5.1 and 5.3 in the case that perennial woody biomass is replaced at or over the year of harvest/maturity under a nominal harvest/maturity cycle assuming that perennial cropland is harvested and regenerated back into perennial cropland. Carbon losses are estimated by multiplying annual area of harvested/replaced cropland by L_{max}. Countries should use L_{mean} in updated Table 5.1 and 5.3 in the case that carbon removal has occurred by land use change where the age of the perennial crop removed is unknown. Carbon losses are estimated by multiplying the annual area of land conversion by L_{mean}. When perennial cropland is converted to another type of cropland, losses are reported in cropland remaining cropland. When perennial cropland is converted to non-cropland land uses, losses are reported in relevant land converted categories

Tiers 2 and 3

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

5.2.1.3 CHOICE OF ACTIVITY DATA

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

Tier 1

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

Tier 2

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

Tier 3

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

TABLE 5.4 (UPDATED[1])
EXAMPLES OF CLASSIFICATION OF PERENNIAL CROP SYSTEMS

	Crop system	Description
Agroforestry	Fallows	Land rested from cultivation, but comprises planted and managed trees, often leguminous, shrubs and herbaceous cover crops before it is cultivated again. Includes improved and natural fallows and can be implemented before any of the following systems.
	Hedgerows	Linear plantation around fields, including shelterbelts, windbreaks, boundary plantings and live fences.
	Alley cropping	Fast-growing, usually leguminous, woody species (mainly shrubs) grown in crop fields, usually at high densities. The woody species are regularly pruned and the prunings are applied as mulch into the alleys as a source of organic matter and nutrients. Also known as intercropping.
	Multistrata systems	Multistorey combinations of a large number of various trees and perennial and annual crops. They include home gardens and agroforests.
	Parklands	Intercropping of agricultural crops or grazing land under low density mature scattered trees. Typical of dry areas like Sahel (e.g. *Faidherbia albida*).
	Shaded perennial-crop systems	Growing shade-tolerant species such as cacao and coffee under, or in between, overstorey shade trees that can be used for timber or other commercial tree products
	Silvoarable systems	Woody species planted in parallel tree rows to allow mechanization and intercropped with an annual crop; usually used for timber (e.p. *Juglans* spp), but also for fuel (e.p. *Populus* spp). Usually low tree density per hectare.
	Silvopastoral systems	Woody species planted on permanent grasslands, often grazed.
Monoculture	Plantations	Monoculture plantation crops such as tea, coffee and cacao grown without shade trees, as well as oil palms, rubber and coconuts.
	Vine systems	A plantation of vines, typically producing grapes used for winemaking, but also kiwifruit or passionfruit.
	Orchards systems	Land planted with woody vegetation, often fruit trees (eg. apple, pear, plum, nut trees). Understory vegetation is usually mowed or grazed.

Source: Cardinael et al (2018), adapted from Nair *et al* (2009)
Within the FAOSTAT land use classification system most perennial crop systems will be classified under 6650 (Land under permanent crops). Fallows may be reported under 6655 (Land with temporary fallow), and parklands and silvopastoral systems under 6655 (Land under permanent meadows and pastures), Land that meets the forest definition will be reported as Forest land.

[1]Updated Table 5.4 in the *2006 IPCC Guidelines*

5.2.1.4 CALCULATION STEPS FOR TIER 1 AND TIER 2

No refinement.

5.2.1.5 UNCERTAINTY ASSESSMENT

No refinement.

5.2.2 Dead organic matter

No refinement.

5.2.3 Soil carbon

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

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

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

5.2.3.1 CHOICE OF METHOD

Inventories can be developed using a Tier 1, 2, or 3 method, with each successive Tier requiring more detail and resources than the previous one. It is also possible that countries will use different tiers to prepare estimates for the separate subcategories of soil C (i.e., soil organic C stocks changes in mineral soils and organic soils, and stock changes associated with soil inorganic C pools). Decision trees are provided for mineral soils (Figure 2.5) and organic soils (Figure 2.6) in Section 2.3.3.1 (Chapter 2) to assist inventory compilers with selection of the appropriate tier for their soil C inventory.

Mineral soils

Tier 1

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

Tier 2

Developing Country-Specific Factors for the Default Equations

For Tier 2, the same basic equations are used as in Tier 1 (Equation 2.25), but country-specific information is incorporated to specify better the stock change factors and reference C stocks with more disaggregation of climate regions, soil types, and/or the land management classification. See Section 2.3.3.1, Chapter 2, Volume IV for more information.

Biochar C Amendments

Tier 2 methods for biochar C amendments utilize a top-down approach in which the total amount of biochar generated and added to mineral soil is used to estimate the change in soil organic C stocks with country-specific factors. See Section 2.3.3.1, Chapter 2, Volume IV for more information.

Steady-State Method

The Tier 2 steady-state method is a three sub-pool steady-state C model that provides an optional alternative method for estimating soil C stock changes in the 0-30 cm layer of mineral soils in *Cropland Remaining Cropland.*[2] This Tier 2 steady-state method estimates C stock changes from combinations of tillage and C-input management activities under conditions defined by the soil texture and the weather. The method is not appropriate for rice cultivation and is not parameterised to estimate the change in soil organic C stocks due to biochar C amendments.

[2] The Tier2 Steady state method may be applicable to other land uses, but this will require further development and parameterisation than provided in this section.

This is an approach with intermediate complexity between Tier 1 and Tier 3 methods, and is based on a steady-state solution to the three soil organic C sub-pools in the Century ecosystem model (Ogle *et al*. 2012; Parton *et al*. 1987; Paustian *et al.* 1997b).

The Tier 2 steady-state method addresses more complexity in soil C dynamics than Tier 1 or Tier 2 using default equations, by subdividing soil organic C into three separate sub-pools with fast (Active sub-pool), intermediate (Slow sub-pool), and long turnover times (Passive sub-pool). The turnover time of C within each sub-pool determines the length of time that C remains in the soil. The Tier 2 steady-state method incorporates spatial and temporal variation in climate, organic carbon inputs to soils, soil properties and management practices. However, compilers can further develop and/or parameterise this model given appropriate datasets, which would be a Tier 3 method (See Section 2.5.2 for more information about developing a Tier 3 model-based approach). See Boxes 5.1A and 5.1B for more information about the method.

BOX 5.1A (NEW)
UNDERSTANDING THE BASIS FOR THE TIER 2 STEADY STATE METHOD

The Tier 2 steady-state method, based on a soil C model, features intermediate complexity between Tier 1 and Tier 3 methods. It allows a compiler to estimate C stock changes in a more disaggregated way compared to Tier 1, but lacks the full complexity of Tier 3 methods. The model parameters were determined using a Bayesian Calibration method (See Annex 5A.3), and application of this method will generate SOC stock change factor that are specific to climate, soil and management conditions in a country. Consequently, the resulting stock change factors are more disaggregated than the default Tier 1 methods that are derived at a global scale with limited disaggregation to broadly-defined climate regions.

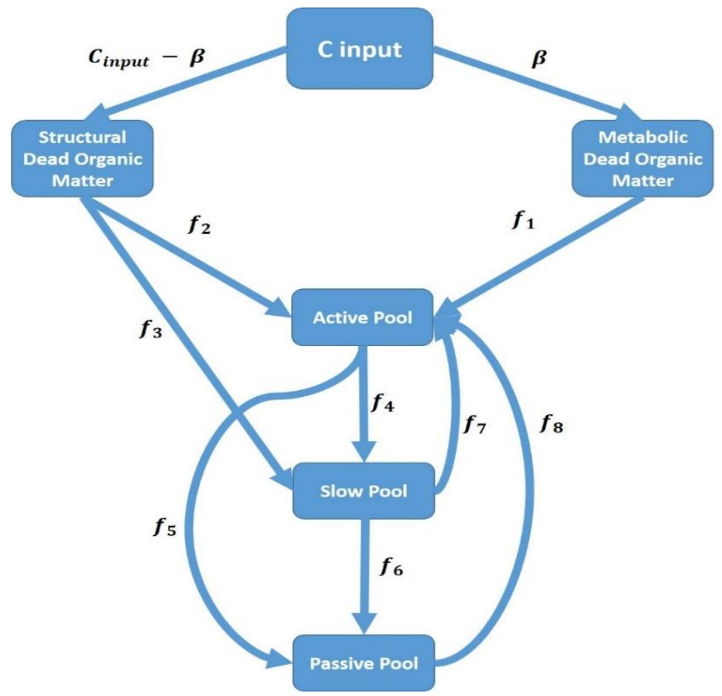
It is noteworthy that Tier 2 methods are often based directly on the Tier 1 equations with country-specific factors, but this is not a requirement for a Tier 2 method (See Volume 4, Chapter 1, Box 1.1). This method is analogous to the Tier 2 methods for estimating CH_4 emissions from enteric fermentation (Volume 4, Chapter 10), with a set of equations for calculating gross energy intake in order to derive a country-specific emission factor. The Tier 2 equations are used to derive stock change factors from country-specific data on crop type, yields, tillage, organic amendments, soil texture, and weather. The Tier 2 steady-state method uses management activity data that are typically more available in a country than that required to apply the methods for the default equations. The method gives the countries with these data an option to develop C stock change that are more responsive to their particular conditions than the Tier 1 approach. The Tier 1 equations require detailed information on the combination of crops types, tillage practices, manure amendments, mineral fertilization, irrigation management, grazing management, green manures, and fallows for individual parcels of land in the inventory. Although several of these activity data are needed for the Tier 2 steady-state method, much of the data requirements with the default equations are represented by the C inputs to the soil that are derived from crop yields, thereby eliminating several data requirements.

This method differs from Tier 3 methods that utilize process-based models that yield a fully dynamic time series by simulating changes in management and environmental conditions through time. This Tier 2 method does not simulate C change but simply calculates an annual C stock change from the current C stock to the future steady-state soil C stock calculated based on current conditions. In addition, the steady-state method is much less complex with about 20 parameters compared to the 100s to 1000s parameters that are often found in Tier 3 process-based models. Consequently, the data and resource requirements are considerably less intensive than typical process-based model applications (See examples in Box 2.2d, Chapter 2, Volume IV).

The Tier 2 steady state method introduces additional interannual variation into the final results compared to Tier 1, by representing the impact of drivers such as weather on C inputs to soils and losses associated with decomposition of soil organic matter. Using this method may require additional quality assurance, quality control and verification (see Volume 1, Chapter 6, Section 6.11).

BOX 5.1B (NEW)
DESCRIPTION OF THE TIER 2 STEADY STATE METHOD FOR ESTIMATING MINERAL SOIL ORGANIC CARBON STOCK CHANGES

The Tier 2 steady-state method is adapted from the Century Ecosystem Model (Parton *et al.* 1987) and estimates changes in soil organic C for the top 30cm of the soil profile. In this model, the stock of the soil carbon sub-pools is initialised by running the model with climate and carbon input data associated for a period of 5-20 years prior to the start of the inventory (or longer if data are available). A proportion of biomass C (C input to the soil) is transferred to soil litter, and then divided into fraction, β, that goes to metabolic components with the remaining fraction (C_{input}- β) going to structural components [1]. The structural component is composed of more recalcitrant, ligno-cellulose plant materials. The metabolic component is composed of more readily decomposed organic matter. Decomposition products are transferred according to calculated fractional transfer coefficients (f_1 to f_8) to and between three soil organic matter sub-pools, active, slow and passive. The active sub-pool is microbial (bacteria and fungi) biomass and associated metabolites with a rapid turnover (months to years), the slow sub-pool has intermediate stability and turnover (decades), and the passive sub-pool is mineral-protected C and microbial decomposition products with long turnover times (centuries). Irrespective of the turnover time the approach is used to estimate the stock of each sub-pool and how they change over time. The total soil organic carbon stock and stock change is calculated as the sum of the values derived for each sub-pool.



Decomposition rates for sub-pools depend on the decay rate constants, temperature effects, and moisture effects. Decomposition of the active and slow sub-pools is also influenced by the soil texture (sand content) and tillage practice. Sub-pools with longer turnover times imply that the C remains in the soil for more years before the organic matter is decomposed and carbon is respired as CO_2 by the soil decomposer community. As decomposition occurs in each sub-pool, some of the decomposing C is transferred to other sub-pools and components (arrows in the diagram) and some of the C is converted into CO_2 and lost from the soil (not identified with arrows). The transfer of C to the next sub-pool or component at steady state is determined by the transfer coefficients (f). Higher transfer coefficients imply that more of the C is transferred to the next sub-pool or component rather than converted into CO_2. The steady-state solution for this model is discussed further in Paustian et al. (1997) and Ogle et al. (2012).

[1] This approach is not intended to be used for estimation of dead organic matter. Compilers should apply the dead organic matter methods in section 5.2.2.

The land base is stratified as fine as possible to include the spatial variation in climate, soil properties, irrigation, and tillage practices. However, there will be practical limits to the level of stratification given the resolution of data and national circumstances for inventory compilation. The method can be applied by subdividing the country into grid cells or regions, such as counties, districts or municipalities. Each grid cell or region would contain a single combination of climate, soil properties and tillage practices and have an area of land assigned to the unit. Within each grid cell or region, the compiler will determine the C input using country-specific equations, or alternatively a generic equation can be used (Equation 5.0h). Compilers will also need values for the parameters defining the quality of the C input (lignin and nitrogen content) or use generic values available in Tables 5.5b and 5.5c. The type of tillage applied within each grid cell or region will need to be compiled to determine the correct value for tillage parameter. Monthly average temperature, precipitation and potential evapotranspiration is needed for each grid cell or region. This information is available from global datasets, such as the Climatic Research Unit (CRU) climate dataset[3], if country-specific data are not available. The average sand content is needed for each grid cell or region, which is available from Harmonized World Soil Database[4] or from Soil Grids[5], if country-specific data are not available. If global data sources are used, it is important to understand and acknowledge the uncertainty associated with these data products to estimate confidence intervals for the resulting changes in soil C stocks.

The following sections provide the equations and steps involved with application of the method within a grid cell or region (e.g., counties, districts or municipalities). The equations estimate water and temperature effects on decomposition; the size of the active, slow and passive soil carbon sub-pools; and the change in total SOC. The values of default parameters are given in Table 5.5a. All constants in the equations are considered globally applicable and should not be altered when applying this Tier 2 steady-state method. The change in soil C stock is calculated annually, multiplied by the area of the grid cell or region and the product summed across all grid cells or regions to determine the annual inventory soil C stock change.

Equations for the Tier 2- Steady State Method for Mineral Soils

Calculate SOC Stock Changes

The change in SOC stock is calculated using Equation 5.0a.

EQUATION 5.0A (NEW)
ANNUAL CHANGE IN SOIL C STOCK FOR MINERAL SOILS USING THE STEADY STATE METHOD

$$\Delta C_{Mineral} = \sum_i F_{SOC_i} \bullet A_i$$

$$F_{SOC_i} = SOC_{yi} - SOC_{(y-1)i}$$

$$SOC_{yi} = ACTIVE_{yi} + SLOW_{yi} + PASSIVE_{yi}$$

Where:

$\Delta C_{Mineral}$ = annual SOC stock change factor for mineral soil, summed across all i grid cells or regions, tonnes C

F_{SOC_i} = annual stock change factor for mineral soils in grid cell or region i, tonnes C ha^{-1}

A_i = Area of grid cell or region i, ha

SOC_{yi} = SOC stock at the end of the current year y for grid cell or region i, tonnes C ha^{-1}

$SOC_{(y-1)i}$ = SOC stock at the end of the previous year for grid cell or region i, tonnes C ha^{-1}

$ACTIVE_{yi}$ = active sub-pool SOC stock in year y for grid cell or region i, tonnes C ha^{-1} (see Equation 5.0b)

$SLOW_{yi}$ = slow sub-pool SOC stock in year y for grid cell or region i, tonnes C ha^{-1} (see Equation 5.0c)

$PASSIVE_{yi}$ = passive sub-pool SOC stock in year y for grid cell or region i, tonnes C ha^{-1} (see Equation 5.0d)

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[3] https://crudata.uea.ac.uk/cru/data/hrg/ (23/10/2018)

[4] http://webarchive.iiasa.ac.at/Research/LUC/External-World-soil-database/HTML/ (23/10/2018)

[5] https://soilgrids.org/#!/?layer=TAXNWRB_250m&vector=1 (23/10/2018)

All subsequent equations associated with the steady state method (Equations 5.0b – 5.0g) are to be completed separately using data derived for each grid cell or region to yield values specific to the grid cell or region. The subscripts i have been left off the equations to simplify the presentation of the equations. All calculations denoted in Equations 5.0b – 5.0g will need to be completed for each individual grid cell or region included in the inventory process.

Calculate the size of the Active SOC Sub-pool

The size of the active SOC sub-pool is calculated using Equation 5.0b. The calculations for each sub-pool

EQUATION 5.0B (NEW)
ACTIVE SUB-POOL SOIL C STOCK FOR MINERAL SOILS USING THE STEADY-STATE METHOD

$$ACTIVE_y = ACTIVE_{y-1} + \left(ACTIVE_{y^*} - ACTIVE_{y-1}\right) \bullet 1yr \bullet k_a$$

$$ACTIVE_{y^*} = \frac{\alpha}{k_a}$$

$$k_a = k_{fac_a} \bullet t_{fac} \bullet w_{fac} \bullet \left(0.25 + \left(0.75 \bullet sand\right)\right) \bullet till_{fac}$$

Where:

$ACTIVE_y$ = active sub-pool SOC stock in year y, tonnes C ha^{-1}

$ACTIVE_{y-1}$ = active sub-pool SOC stock in previous year, tonnes C ha^{-1}

$ACTIVE_{y^*}$ = steady state active sub-pool SOC stock given conditions in year y, tonnes C ha^{-1}

k_a = decay rate for active SOC sub-pool, $year^{-1}$

α = C input to the active SOC sub-pool, tonnes C ha^{-1} $year^{-1}$ (see Equation 5.0g)

k_{fac_a} = decay rate constant under optimal conditions for decomposition of the active SOC sub-pool, $year^{-1}$ (see Table 5.5a)

t_{fac} = temperature effect on decomposition, dimensionless (see Equation 5.0e)

w_{fac} = water effect on decomposition, dimensionless (see Equation 5.0f)

$till_{fac}$ = tillage disturbance modifier on decay rate for active and slow sub-pools, dimensionless (see Table 5.5a)

$sand$ = fraction of 0-30 cm soil mass that is sand (0.050 – 2mm particles), dimensionless

NOTE: If the estimated k_a value is above 1, then set the value of k_a to 1 in the equation for calculating $ACTIVE_y$ in the first equation. The ‘1 year’ designation in the equation is because the model is applied to estimate changes over a single year, which is needed so that units cancel appropriately in the calculation.

Calculate the size of the Slow SOC Sub-pool

The size of the slow SOC sub-pool is calculated using Equation 5.0c.

EQUATION 5.0C (NEW)
SLOW SUB-POOL SOIL C STOCK FOR MINERAL SOILS USING THE STEADY-STATE METHOD

$$SLOW_y = SLOW_{y-1} + \left(SLOW_{y^*} - SLOW_{y-1}\right) \bullet 1yr \bullet k_s$$

$$SLOW_{y^*} = \frac{[\left(C_{input} \bullet LC\right) \bullet f_3] + \left[\left(ACTIVE_{y^*} \bullet k_a\right) \bullet f_4\right]}{k_s}$$

$$k_s = k_{fac_s} \bullet t_{fac} \bullet w_{fac} \bullet till_{fac}$$

$$f_4 = 1 - f_5 - \left(0.17 + 0.68 \bullet sand\right)$$

Where:

$SLOW_y$ = slow sub-pool SOC stock in y, tonnes C ha^{-1}

$SLOW_{y-1}$ = slow sub-pool SOC stock in previous year, tonnes C ha^{-1}

$SLOW_{y^*}$ = steady state slow sub-pool SOC stock given conditions in year y, tonnes C ha^{-1}

k_s = decay rate for slow SOC sub-pool, year^{-1}

C_{input} = total carbon input, tonnes C ha^{-1} year^{-1}

LC = lignin content of carbon input, proportion (see Table 5.5b and 5.5c) for default values, otherwise compile country-specific values)

$ACTIVE_{y^*}$ = steady state active sub-pool SOC stock given conditions in year y, tonnes C ha^{-1}

k_a = decay rate for active carbon sub-pool in the soil, year^{-1}

k_{fac_s} = decay rate constant under optimal condition for decomposition of the slow carbon sub-pool, year^{-1} (see Table 5.5a)

t_{fac} = temperature effect on decomposition, dimensionless (see Equation 5.0e)

w_{fac} = water effect on decomposition, dimensionless (see Equation 5.0f)

$till_{fac}$ = tillage disturbance modifier on decay rate for active and slow sub-pools, dimentionless (see Table 5.5a)

f_3 = fraction of structural component decay products transferred to the slow sub-pool, proportion (see Table 5.5a)

f_4 = fraction of active sub-pool decay products transferred to the slow sub-pool, proportion (see Equation 5.0c)

f_5 = fraction of active sub-pool decay products transferred to the passive sub-pool, proportion (see Table 5.5a)

$sand$ = fraction of 0-30 cm soil mass that is sand (0.050 – 2mm particles), proportion

NOTE: If the estimated k_s value is above 1, then set the value of k_s to 1 in the equation for calculating $SLOW_y$ in the first equation. The '1 year' designation in the equation is because the model is applied to estimate changes over a single year, which is needed so that units cancel appropriately in the calculation.

Calculate the size of the Passive C Sub-pool

The size of the slow SOC sub-pool is calculated using Equation 5.0d.

EQUATION 5.0D (NEW)
PASSIVE SUB-POOL SOIL C STOCK FOR MINERAL SOILS USING THE STEADY-STATE METHOD

$$PASSIVE_y = PASSIVE_{y-1} + \left(PASSIVE_{y^*} - PASSIVE_{y-1}\right) \bullet 1yr \bullet k_p$$

$$PASSIVE_{y^*} = \frac{\left[\left(ACTIVE_{y^*} \bullet k_a\right) \bullet f_5\right] + \left[\left(SLOW_{y^*} \bullet k_s\right) \bullet f_6\right]}{k_p}$$

$$k_P = k_{fac_p} \bullet t_{fac} \bullet w_{fac}$$

Where:

$PASSIVE_y$ = passive sub-pool SOC stock in year y, tonnes C ha^{-1}

$PASSIVE_{y-1}$ = passive sub-pool SOC stock in previous year, tonnes C ha^{-1}

$PASSIVE_{y^*}$ = steady state passive sub-pool SOC given conditions in year y, tonnes C ha^{-1}

k_P = decay rate for passive SOC sub-pool, year^{-1}

$ACTIVE_{y^*}$ = steady state active sub-pool SOC stock given conditions in year y, tonnes C ha^{-1}

k_a = decay rate for active carbon sub-pool, year^{-1}

$SLOW_{y^*}$ = steady state slow sub-pool SOC stock given conditions in year y, tonnes C ha^{-1}

k_s = decay rate for slow carbon sub-pool, year^{-1}

k_{fac_p} = decay rate constant under optimal conditions for decomposition of the slow carbon sub-pool, year^{-1} (see Table 5.5a)

t_{fac} = temperature effect on decomposition, dimensionless (see Equation 5.0e)

w_{fac} = water effect on decomposition, dimensionless (see Equation 5.0f)

f_5 = fraction of active sub-pool decay products transferred to the slow sub-pool, proportion(see Table 5.5a)

f_6 = fraction of slow sub-pool decay products transferred to the passive sub-pool, proportion(see Table 5.5a)

NOTE: If the estimated k_p value is above 1, then set the value of k_p to 1 in the equation for calculating $PASSIVE_y$ in the first equation. The '1 year' designation in the equation is because the model is applied to estimate changes over a single year, which is needed so that units cancel appropriately in the calculation.

Calculate Temperature Effect on Decomposition

Calculate the temperature effect on soil organic matter decomposition using Equation 5.0e.

EQUATION 5.0E (NEW)
TEMPERATURE EFFECT ON DECOMPOSITION FOR MINERAL SOILS USING THE STEADY-STATE METHOD

$$t_{fac} = \frac{1}{12}\sum_{i=1}^{12} T_i$$

$$T_i = \left(\frac{t_{max} - temp_i}{t_{max} - t_{opt}}\right)^{0.2} \bullet exp\left\{0.076 \bullet \left[1 - \left(\frac{t_{max} - temp_i}{t_{max} - t_{opt}}\right)^{2.63}\right]\right\}$$

Where:

t_{fac} = annual average air temperature effect on decomposition, dimensionless

T_i = monthly average air temperature effect on decomposition, dimensionless (i = 1, 2, …, 12)

t_{max} = maximum monthly air temperature for decomposition, degrees C (see Table 5.5a)

$temp_i$ = monthly average air temperature (i = 1, 2, …, 12), degrees C

t_{opt} = optimum air temperature for decomposition, degrees C (see Table 5.5a)

NOTE: When the monthly average air temperature is greater than 45 °C (i.e., the maximum average air temperature) set T_i to 0.

Calculate Water Effect on Decomposition

Estimate the water effect on soil organic matter decomposition using Equation 5.0f

EQUATION 5.0F (NEW)
WATER EFFECT ON DECOMPOSITION FOR MINERAL SOILS USING THE STEADY-STATE METHOD

$$w_{fac} = 1.5 \bullet \left(\frac{1}{12}\sum_{i=1}^{12} w_i\right)$$

$$w_i = 0.2129 + \left(w_s \bullet mappet_i\right) - \left(0.2413 \bullet mappet_i^{\,2}\right)$$

$$mappet_i = \min\left(1.25, \frac{precip_i}{PET_i}\right)$$

Where:

w_{fac} = annual water effect on decomposition, dimensionless

w_i = monthly water effect on decomposition, dimensionless

w_s = modifier for $mappet_i$, dimensionless (see Table 5.5a)

$mappet_i$ = ratio of total precipitation to total potential evapotranspiration (dimensionless) for month i (i = 1, 2, …12)

$precip_i$ = total precipitation for month i, mm

PET_i = total potential evapotranspiration for month i, mm

NOTE: If the $mappet_i$ is >1.25, then set the value of $mappet_i$ for the month to 1.25 for non-irrigated system (i.e., $mappet_i$ does not exceed 1.25). Set w_i for months with irrigation to 0.775.

Calculate C Input to the Active Sub-pool

Calculate alpha value using Equation 5.0g, which is the C input to the active SOC sub-pool.

EQUATION 5.0G (NEW)
C INPUT TO THE ACTIVE SOIL C SUB-POOL FOR MINERAL SOILS USING THE STEADY-STATE METHOD

$$\alpha = \frac{[\beta \bullet f_1] + \left[\left(C_{input} \bullet (1-LC) - \beta\right) \bullet f_2\right] + \left[\left(C_{input} \bullet LC\right) \bullet f_3 \bullet (f_7 + f_6 \bullet f_8)\right]}{1-(f_4 \bullet f_7)-(f_5 \bullet f_8)-(f_4 \bullet f_6 \bullet f_8)}$$

$$\beta = C_{input} \bullet \left[0.85 - 0.018 \bullet \left(\frac{LC}{NC}\right)\right]$$

Where:

α = C input to the active soil carbon sub-pool, tonnes C ha^{-1}

β = C input to the metabolic dead organic matter C component, tonnes C ha^{-1} $year^{-1}$

C_{input} = total carbon input, tonnes C $ha^{-1}year^{-1}$

f_1 = fraction of metabolic dead organic matter decay products transferred to the active sub-pool, proportion (see Table 5.5a)

f_2 = fraction of structural dead organic matter decay products transferred to the active sub-pool, proportion (see Table 5.5a)

f_3 = fraction of structural dead organic matter decay products transferred to the slow sub-pool, proportion (see Table 5.5a)

f_4 = fraction of active sub-pool decay products transferred to the slow sub-pool, proportion, (see Equation 5.0c)

f_5 = fraction of active sub-pool decay products transferred to the passive sub-pool, proportion (see Table 5.5a)

f_6 = fraction of slow sub-pool decay products transferred to the passive sub-pool, proportion (see Table 5.5a)

f_7 = fraction of slow sub-pool decay products transferred to the active sub-pool, proportion (see Table 5.5a)

f_8 = fraction of passive sub-pool decay products transferred to the active sub-pool, proportion (see Table 5.5a)

LC = lignin content of carbon input, proportion (see Tables 5.5b and 5.5c for default values, otherwise compile country-specific values)

NC = nitrogen fraction of the carbon input, proportion (see Tables 5.5b and 5.5c) for default values, otherwise compile country-specific values)

Table 5.5A provides the default parameters, minimum and maximum values for parameters, and their associated standard deviation. The probability distribution functions for the parameters should be constructed as truncated normal distributions, in which parameter values lower than the minimum value are constrained the minimum value, and parameter values greater than the maximum values are constrained to the maximum value. Uncorrelated draws from the probability distribution functions of the parameters can be made using the data in this table, but more robust estimates of uncertainty can be made using a truncated joint probability distribution with the parameter covariance matrix found in Annex 2A.3

Step-by-Step procedure for implementing the Tier2 steady-state method for Mineral Soils

Steps 1 to 8 are conducted for each grid cell or region, depending on the spatial unit of the inventory. Step 9 sums the changes across the entire spatial domain[6].

Step 1. Calculate the Initial Stocks of the Active, Slow and Passive SOC sub-pools

The initial stocks are calculated based on the climatic, soil texture, management and carbon input data for a run-in period[7] of 5 to 20 years (more years may be used if data are available).

Step 1.1: Calculate the average annual values of t_{fac} (Equation 5.0e) and w_{fac} (Equation 5.0f) for the run-in period.

Step 1.2: Calculate the C input to the active sub-pool (α) for the run-in period (Equation 5.0g) using the following data:

a. the average annual carbon input (C_{input}) for the run-in period, which may be estimated with Equation 5.0h if country-specific methods are not available,
b. the appropriate values for *LC* and *NC* for the crop and/or grass in place during the run-in period can be found in the Tier2 steady-state method section for cropland (see Section 5.2.3.2 for cropland default values, otherwise compile country-specific values),
c. the value of f_2 from Table 5.5a, and
d. the sand content of the 0-30 cm soil layer ($sand$).

Step 1.3: Calculate the values of k_a (Equation 5.0b), k_s (Equation 5.0c) and k_p (Equation 5.0d) using:

a. the average values of t_{fac} and w_{fac} calculated in Step 1.1,
b. the values of k_{fac_a} , k_{fac_s} , k_{fac_p} and the appropriate tillage factor ($till_{fac}$) from Table 5.5A, and
c. the sand content of the 0-30 cm soil layer ($sand$).

Step 1.4: Calculate the values for $ACTIVE_y$ (Equation 5.0b), $SLOW_y$ (Equation 5.0c) and $PASSIVE_y$ (Equation 5.0d) for the run-in period, which become the initial SOC stocks for the ACTIVE, SLOW and PASSIVE SOC sub-pools at the commencement of the inventory period.

Step 2. Calculate C Input to the Active Sub-pool for each year of the inventory period

Calculate value of α (the C input to the active SOC sub-pool) for each year in the inventory period using Equation 5.0g.

Step 2.1: Calculate the C input to the metabolic dead organic matter component (β).

Step 2.2: Calculate the C input to the active soil carbon sub-pool (α).

Step 2.3: Repeat Steps 2.1 to 2.2 for all other years in the inventory period to derive annual values for β and α .

Step 3. Calculate Water Effect on Decomposition

Estimate the water effect on soil organic matter decomposition using Equation 5.0f.

Step 3.1: For each month in a year, calculate the ratio of total precipitation to total potential evapotranspiration.

a. If the ratio is ≤1.25 then set the value of $mappet_i$ for the month to the estimated ratio.
b. If the ratio is >1.25 then set the value of $mappet_i$ for the month to 1.25.
c. Set w_i for months with irrigation to 0.775.

Step 3.2: Calculate water effect on decomposition for each month (w_i) in a year. For land area under irrigation management, set the water effect on decomposition for the month (w_i) to 0.775.

Step 3.3: Calculate the annual water effect on decomposition (w_{fac}).

[6] An example of the Tier 2 steady state method is provided in a supplementary file, V4_Ch5_Tier2_Steady_State_Method.xlsx

[7] Compilers can use longer run-in periods than 20 years to establish the initial soil organic C stocks for the inventory, but 5 years is considered a minimum period of time for this method. Initial values of the active, slow and passive pools can lead to biases in results if the run-in period is not long enough to capture the trajectory of the stocks based on legacy effects associated with historical land use and management.

Step 3.4: Repeat steps 3.1 to 3.3 to calculate the water effect (w_{fac}) on decomposition for all years in the inventory period.

Step 4. Calculate Temperature Effect on Decomposition

Calculate the temperature effect on soil organic matter decomposition using Equation 5.0e.

Step 4.1: For each month in a year, calculate temperature effect on decomposition (T_i) using the values for maximum monthly temperature for decomposition (t_{max}), optimum temperature for decomposition (t_{opt}) and the monthly average temperature ($temp_i$).

a. If the monthly average temperature is ≤45 °C, use the calculated value of T_i .

b. If the monthly average temperature is >45 °C, set T_i equal to 0.

Step 4.2: Calculate annual temperature effect on decomposition (t_{fac}).

Step 4.3: Repeat steps 4.1 and 4.2 to calculate the annual temperature effect on decomposition for all years in the inventory.

Step 5. Calculate the size of the Passive C Sub-pool

Calculate the size of the passive sub-pool using Equation 5.0d.

Step 5.1: Calculate decay rate for the PASSIVE SOC sub-pool in the soil *(* k_p).

Step 5.2: Calculate the steady state stock for the PASSIVE sub-pool SOC stock ($PASSIVE_{y*}$).

Step 5.3: Calculate the PASSIVE sub-pool SOC stock by determining the additional increase or decrease in SOC from the previous year in the inventory ($PASSIVE_y$). Note that the initial size of the PASSIVE SOC sub-pool used at the start of the inventory period is calculated as defined in step 1. Note also that if the estimated k_p value is above 1, then set the value of k_p to 1 in the equation for calculating $PASSIVE_y$.

Step 5.4: Repeat steps 5.1 to 5.3 to calculate the PASSIVE SOC stocks for all years in the inventory.

Step 6. Calculate the size of the SLOW SOC Sub-pool

Calculate the size of the slow sub-pool using Equation 5.0c.

Step 6.1: Calculate decay rate for SLOW SOC sub-pool in the soil (k_s).

Step 6.2: Calculate the steady state stock for the SLOW SOC sub-pool ($SLOW_{y*}$).

Step 6.3: Calculate the SLOW SOC stock by determining the additional increase or decrease in SOC from the previous year in the inventory ($SLOW_y$ **)**. Note that the initial size of the SLOW SOC sub-pool used at the start of the inventory period is calculated as defined in step 1. Note also that if the estimated k_s value is above 1, then set the value of k_s to 1 in the equation for calculating $SLOW_y$ **)**.

Step 6.4: Repeat steps 6.1 to 6.3 to calculate the SLOW SOC sub-pool stocks for all years in the inventory.

Step 7. Calculate the size of the ACTIVE SOC Sub-pool

Calculate the size of the active sub-pool using Equation 5.0b.

Step 7.1: Calculate decay rate for the ACTIVE SOC sub-pool in the soil (k_a).

Step 7.2: Calculate the steady state stock for the ACTIVE SOC sub-pool ($ACTIVE_{y*}$).

Step 7.3: Calculate the ACTIVE SOC stock by determining the additional increase or decrease in SOC from the previous year in the inventory ($ACTIVE_y$). Note that the initial size of the ACTIVE SOC sub-pool used at the start of the inventory period is calculated as defined in step 1. Also note that if the estimated k_a value is above 1, then set the value of k_a to 1 in the equation for calculating ($ACTIVE_y$).

Step 7.4: Repeat Steps 7.1 to 7.3 to calculate the ACTIVE SOC sub-pool stocks for all years in the inventory.

Step 8. Calculate the total annual SOC stock change

Step 8.1: Calculate the SOC stock (SOC_y) for each grid cell or region by summing the SOC in the ACTIVE, SLOW and PASSIVE sub-pools ($ACTIVE_y$, $SLOW_y$ and $PASSIVE_y$, respectively) using Equation 5.0a.

Step 8.2: Calculate the stock change factor (F_{SOC_i}) for each grid cell or region using Equation 5.0a.

Step 8.3: Calculate the total change in SOC stock ($\Delta C_{Mineral}$) using Equation 5.0a by multiplying the stock change factor (F_{SOC_i}) by the area of the grid cell or region i (A), and summing the changes across all land included in the Tier 2 steady-state method.

Tier 3

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

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

For biochar C amendments to soils, Tier 3 methods can be used to address GHG sources and sinks not captured in Tiers 1 or 2, such as priming effects, changes to N_2O or CH_4 fluxes from soils, and changes to net primary production. More information on Tier 3 methods is provided in Section 2.3.3.1 of Chapter 2, Volume IV.

Organic soils

No refinement.

The *2013 Supplement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories: Wetlands* provides additional guidance that updates the *2006 IPCC Guidelines for national Greenhouse Gas Inventories*. See section 2.2 of the *2013 Wetlands Supplement covers Tier 1, 2, and 3 approaches for drained organic soils in cropland.*

5.2.3.2 CHOICE OF STOCK CHANGE AND EMISSION FACTORS

Mineral soils

Tier 1

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

Tier 2

Developing Country-Specific Factors for the Default Equations

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

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

Factor value type	Level	Temper-ature regime	Moisture regime[1]	IPCC defaults	Error [2,3]	Description
Land use[5] (F_{LU})	Long-term cultivated	Cool Tem-perate/ Boreal	Dry	0.77	±14%	Represents area that has been converted from native conditions and continuously managed for predominantly annual crops over 50 yrs. Land-use factor has been estimated under a baseline condition of full tillage and nominal ('medium") carbon input levels. Input and tillage factors are also applied to estimate carbon stock changes, which includes changes from full tillage and medium input.
			Moist	0.70	±12%	
		Warm Temperate	Dry	0.76	±12%	
			Moist	0.69	±16%	
		Tropical	Dry	0.92	±13%	
			Moist/Wet	0.83	±11%	
Land use[6] (F_{LU})	Paddy rice	All	Dry and Moist/Wet	1.35	±4%	Long-term (> 20 year) annual cropping of wetlands (paddy rice). Can include double-cropping with non-flooded crops. For paddy rice, tillage and input factors are not used.
Land use[5] (F_{LU})	Perennial/ Tree Crop	Temperate/ Boreal	Dry and Moist	0.72	±22%	Long-term perennial tree crops such as fruit and nut trees, coffee and cacao.
		Tropical	Dry and Moist/Wet	1.01	±25%	
Land use (F_{LU})	Set aside (< 20 yrs)	Temperate/ Boreal and Tropical	Dry	0.93	±11%	Represents temporary set aside of annually cropland (e.g., conservation reserves) or other idle cropland that has been revegetated with perennial grasses.
			Moist/Wet	0.82	±17%	
		Tropical montane[44]	n/a	0.88	±50%	
Tillage (F_{MG})	Full	All	Dry and Moist/Wet	1.00	n/a	Substantial soil disturbance with full inversion and/or frequent (within year) tillage operations. At planting time, little (e.g., <30%) of the surface is covered by residues.
Tillage[7] (F_{MG})	Re-duced	Cool Tem-perate/ Boreal	Dry	0.98	±5%	Primary and/or secondary tillage but with reduced soil disturbance (usually shallow and without full soil inversion). Normally leaves surface with >30% coverage by residues at planting.
			Moist	1.04	±4%	
		Warm Temperate	Dry	0.99	±3%	
			Moist	1.05	±4%	
		Tropical	Dry	0.99	±7%	
			Moist/Wet	1.04	±7%	
Tillage[7] (F_{MG})	No-till	Cool Tem-perate/ Boreal	Dry	1.03	±4%	Direct seeding without primary tillage, with only minimal soil disturbance in the seeding zone. Herbicides are typically used for weed control.
			Moist	1.09	±4%	
		Warm Temperate	Dry	1.04	±3%	
			Moist	1.10	±4%	
		Tropical	Dry	1.04	±7%	
			Moist/Wet	1.10	±5%	

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

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

Notes: Long-term cultivation, perennial crops paddy rice and tillage management factors were derived using methods provided in Annex 5A1.

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

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

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

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

Sources:

[5] The following references used for land-use factors (other than paddy rice): Aborisade and Aweto, 1990; Adachi *et al.*, 2006; Agbenin and Goladi, 1997; Aina, 1979; Alcantara *et al.*, 2004; Allen, 1985; An *et al.*, 2003; Ashagrie *et al.*, 2005; Assad *et al.*, 2013; Aweto, 1981; Aweto and Ayuba, 1988; Aweto and Ayuba, 1993; Aweto and Ishola, 1994; Ayanaba *et al.*, 1976; Banaticla and Lasco, 2006; Bashkin and Binkley, 1998; Batlle-Bayer *et al.*, 2010; Bautista-Cruz and del Castillo, 2005; Berhongaray *et al.*, 2013; Bernardi *et al.*, 2007; Bernhardreversat, 1988; Berthrong *et al.*, 2012; Bertol and Santos, 1995; Beyer, 1994; Binkley *et al.*, 2004; Binkley and Resh, 1999; Bonde *et al.*, 1992; Bowman and Anderson, 2002; Brand and Pfund, 1998; Brown and Lugo, 1990; Bruun *et al.*, 2006; Burke *et al.*, 1995; Burke *et al.*, 1995; Buschbacher *et al.*, 1988; Buschiazzo *et al.*, 1998; Buyanovksy *et al.*, 1987; Cadisch *et al.*, 1996; Cai *et al.*, 2008; Cambardella and Elliott, 1994; Cambardella and Elliott, 1992; Campos *et al.*, 2007; Cao *et al.*, 2004; Carvalho *et al.*, 2009; Carvalho *et al.*, 2009; Cerri *et al.*, 1991; Cerri *et al.*, 2003; Cerri *et al.*, 2007; Chan, 1997; Chandran *et al.*, 2009; Chen *et al.*, 2007; Chen, 2006; Chia *et al.*, 2017; Chidumayo and Kwibisa, 2003; Chiti *et al.*, 2014; Chone *et al.*, 1991; Cleveland *et al.*, 2003; Collins *et al.*, 1999; Conant *et al.*, 2001; Conti *et al.*, 2014; Cook *et al.*, 2014; Corazza *et al.*, 1999; D'Annunzio *et al.*, 2008; da Silva-Junior *et al.*, 2009; Dai *et al.*, 2008; Dai *et al.*, 2008; Dalal *et al.*, 2005; Dalal and Mayer, 1986; Dawoe *et al.*, 2014; de Blecourt *et al.*, 2013; de Camargo *et al.*, 1999; de Freitas *et al.*, 2000; de Koning *et al.*, 2003; de Moraes *et al.*, 2002; de Moraes *et al.*, 1996; de Neergaard *et al.*, 2008; Dechert *et al.*, 2004; Delelegn *et al.*, 2017; Denef *et al.*, 2007; Desjardins *et al.*, 1994; Desjardins *et al.*, 2004; Detwiler, 1986; Eaton and Lawrence, 2009; Eclesia *et al.*, 2012; Eden *et al.*, 1990; Ekanade, 1991; Elliott *et al.*, 1991; Elmore and Asner, 2006; England *et al.*, 2016; Epron *et al.*, 2009; Erickson *et al.*, 2001; Fabrizzi *et al.*, 2009; Farley *et al.*, 2004; Feldpausch *et al.*, 2004; Feller *et al.*, 2001; Fernandes *et al.*, 2002; Fernandez *et al.*, 2012; Fisher *et al.*, 1994; Follett *et al.*, 1997; Freibauer, 1996; Freixo *et al.*, 2002; Fu *et al.*, 2000; Fu *et al.*, 2001;

TABLE 5.5 (UPDATED) (CONTINUED) **RELATIVE CARBON STOCK CHANGE FACTORS (F_{LU}, F_{MG}, AND F_I) (OVER 20 YEARS) FOR MANAGEMENT ACTIVITIES ON CROPLAN**
Fu *et al.*, 2003; Fuhrmann *et al.*, 1999; Fujisaka *et al.*, 1998; Gamboa and Galicia, 2011; Garcia-Franco *et al.*, 2014; Garcia-Oliva *et al.*, 1994; Garcia-Oliva *et al.*, 2006; Garcia-Oliva *et al.*, 1999; Geissen *et al.*, 2009; Ghuman *et al.*, 1991; Girma, 1998; Gong *et al.*, 2004; Gosling *et al.*, 2017; Gregorich *et al.*, 1996; Guggenberger and Zech, 1999; Han *et al.*, 2004; Han *et al.*, 2005; Harden *et al.*, 1999; Hartemink, 1997; He *et al.*, 2006; Hertl *et al.*, 2009; Hölscher *et al.*, 1997; Hou *et al.*, 2008; Hsieh, 1996; Hu *et al.*, 2007; Huang *et al.*, 2007; Hughes *et al.*, 2000; Hughes *et al.*, 2002; Hughes *et al.*, 2000; Ihori *et al.*, 1995; Ishizuka *et al.*, 2005; Islam and Weil, 2000; Jakelaitis *et al.*, 2008; Janssen and Wienk, 1990; Jaramillo *et al.*, 2003; Jia *et al.*, 2004; Jia *et al.*, 2007; Jimenez *et al.*, 2007; Jun and Liqing, 2007; Juo *et al.*, 1995; Juo and Lal, 1977; Juo and Lal, 1979; Kainer *et al.*, 1998; Karhu *et al.*, 2011; Kawanabe *et al.*, 2000; Keith *et al.*, 2015; King and Campbell, 1994; Kotto-Same *et al.*, 1997; Koutika *et al.*, 1997; Krishnaswamy and Richter, 2002; Lal, 1998; Lemenih *et al.*, 2005; Lemenih *et al.*, 2005; Lemma *et al.*, 2006; Lepsch *et al.*, 1994; Li *et al.*, 2005; Li *et al.*, 2007; Li *et al.*, 2007; Li *et al.*, 2007; Lilienfein *et al.*, 2003; Lima *et al.*, 2006; Lisboa *et al.*, 2009; Lugo and Sanchez, 1986; Luizao *et al.*, 1992; Ma *et al.*, 2006; Macedo *et al.*, 2008; Maia *et al.*, 2009; Makumba *et al.*, 2007; Manlay *et al.*, 2002; Manlay *et al.*, 2002; Maquere *et al.*, 2008; Marin-Spiotta *et al.*, 2009; Markewitz *et al.*, 2004; Martins *et al.*, 2009; Masto *et al.*, 2008; Materechera and Mkhabela, 2001; McGrath *et al.*, 2001; Mendham *et al.*, 2003; Mikhailova *et al.*, 2000; Morris, 1984; Motavalli *et al.*, 2000; Motavalli and McConnell, 1998; Muller *et al.*, 2001; Mutuo *et al.*, 2005; Nadal-Romero *et al.*, 2016; Navarrete *et al.*, 2016; Navarrete and Tsutsuki, 2008; Neill *et al.*, 1997; Neill *et al.*, 1997; Neufeldt *et al.*, 2002; Ogunkunle and Eghaghara, 1992; Ohta, 1990; Osher *et al.*, 2003; Parfitt *et al.*, 1997; Paul *et al.*, 2008; Pennock and van Kessel, 1997; Perrin *et al.*, 2014; Piccolo *et al.*, 2008; Potter *et al.*, 1999; Potvin *et al.*, 2004; Powers, 2004; Powers and Veldkamp, 2005; Rangel *et al.*, 2007; Rasiah *et al.*, 2004; Reeder *et al.*, 1998; Reiners *et al.*, 1994; Resh *et al.*, 2002; Rhoades *et al.*, 2000; Richards *et al.*, 2007; Riezebos and Loerts, 1998; Rojas *et al.*, 2016; Roscoe and Buurman, 2003; Rossi *et al.*, 2009; Russell *et al.*, 2007; Sa *et al.*, 2001; Saggar *et al.*, 2001; Saha *et al.*, 2009; Saha *et al.*, 2010; Salimon *et al.*, 2004; Sanchez *et al.*, 1983; Saynes *et al.*, 2005; Schedlbauer and Kavanagh, 2008; Schiffman and Johnson, 1989; Schwendenmann and Pendall, 2006; Shang and Tiessen, 1997; Sheng *et al.*, 2004; Siband, 1974; Silva *et al.*, 2009; Silver *et al.*, 2004; Sitompul *et al.*, 2000; Six *et al.*, 1998; Six *et al.*, 2000; Slobodian *et al.*, 2002; Smiley and Kroschel, 2008; Smith *et al.*, 2002; Sohng *et al.*, 2017; Solomon *et al.*, 2002; Solomon *et al.*, 2007; Solomon *et al.*, 2000; Sommer *et al.*, 2000; Sparling *et al.*, 2000; Srivastava and Singh, 1991; Su, 2007; Su *et al.*, 2006; Su *et al.*, 2004; Su *et al.*, 2002; Su *et al.*, 2004; Szott and Palm, 1996; Templer *et al.*, 2005; Tian *et al.*, 2001; Tian *et al.*, 2008; Tiessen *et al.*, 1992; Tiessen *et al.*, 1982; Tornquist *et al.*, 1999; Townsend *et al.*, 1995; Trouve *et al.*, 1994; Trumbore *et al.*, 1995; Uhl and Jordan, 1984; Unger, 2001; Vagen *et al.*, 2006; van Dam *et al.*, 1997; van Noordwijk *et al.*, 1997; van Straaten *et al.*, 2015; Veldkamp, 1994; Veldkamp *et al.*, 2003; Villarino *et al.*, 2014; Voroney *et al.*, 1981; Wadsworth *et al.*, 1988; Wairu and Lal, 2003; Walker and Desanker, 2004; Wang *et al.*, 2004; Wang and Zhang, 2009; Wang *et al.*, 2011; Wang *et al.*, 2005; Wang *et al.*, 2006; Wang *et al.*, 2007; Wang *et al.*, 2006; Wang *et al.*, 2008; Weaver *et al.*, 1987; Wick *et al.*, 2000; Wick *et al.*, 2005; Wu and Tiessen, 2002; Wu *et al.*, 2006; Xu *et al.*, 2013; Yan *et al.*, 2008; Yang *et al.*, 2004; Yang *et al.*, 2016; Yemefack *et al.*, 2006; Yin *et al.*, 2008; Yonekura *et al.*, 2010; Yu *et al.*, 2007; Yue *et al.*, 2007; Zhan *et al.*, 2005; Zhang *et al.*, 1988; Zhao *et al.*, 2005; Zhou *et al.*, 2007; Zingore *et al.*, 2005; Zinn *et al.*, 2005; Zinn *et al.*, 2002; Zou and Bashkin, 1998
[6] The following references were used for paddy rice land-use factor: Andreetta *et al.*, 2016; Bi *et al.*, 2009; Gami *et al.*, 2001; Hao *et al.*, 2008; Huang *et al.*, 2015; Kölbl *et al.*, 2014; Liu *et al.*, 2003; Majumder *et al.*, 2008; Mandal *et al.*, 2007; Nayaka *et al.*, 2012; Nayaka *et al.*, 2009; Pampolino *et al.*, 2008; Pan *et al.*, 2009; Shen *et al.*, 2007; Shirato *et al.*, 2011; Shirato and Yokozawa, 2005; Wang *et al.*, 2011; Wu *et al.*, 2000; Xu *et al.*, 2007; Zhang *et al.*, 2006
[7] The following references were used for tillage management factors: Ahl *et al.*, 1998; Al-Kaisi *et al.*, 2005; Al-Kaisi *et al.*, 2005; Alvarez *et al.*, 2014; Alvarez *et al.*, 1998; Alvarez *et al.*, 1995; Alvarez *et al.*, 1998; Alvarez *et al.*, 1995; Alvarez *et al.*, 1995; Alvarez *et al.*, 1995; Alvaro-Fuentes *et al.*, 2009; Alvaro-Fuentes *et al.*, 2008; Alvaro-Fuentes *et al.*, 2014; Angers *et al.*, 1997; Angers *et al.*, 1995; Anken *et al.*, 2004; Balesdent *et al.*, 1990; Barber *et al.*, 1996; Bayer *et al.*, 2006; Bayer *et al.*, 2000; Bayer *et al.*, 2002; Beare *et al.*, 1994; Bhattacharyya *et al.*, 2008; Bhattacharyya *et al.*, 2013; Bhattacharyya *et al.*, 2009; Black and Tanaka, 1997; Blanco-Canqui *et al.*, 2004; Blanco-Canqui *et al.*, 2011; Boddey *et al.*, 2010; Bordovsky *et al.*, 1999; Borin *et al.*, 1997; Borresen and Njos, 1993; Bowman and Anderson, 2002; Bowman and Anderson, 2002; Burch *et al.*, 1986; Buschiazzo *et al.*, 1998; Buyanovsky and Wagner, 1998; 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Fettell and Gill, 1985; Fleige and Baeumer, 1974; Follett and Peterson, 1988; Franzleubbers *et al.*, 1995; Franzluebbers and Arshad, 1996; Franzluebbers *et al.*, 1999; Franzluebbers and Stuedemann, 2002; Freitas *et al.*, 2000; Freixo *et al.*, 2002; Gál *et al.*, 2007; Galantini *et al.*, 2006; Garcia-Prechac *et al.*, 2004; Ghimire *et al.*, 2012; Ghuman and Sur, 2001; Grabski *et al.*, 1997; Green *et al.*, 2007; Gwenzi *et al.*, 2009; Halvorson *et al.*, 1997; Halvorson *et al.*, 2002; Hansmeyer *et al.*, 1997; Hao *et al.*, 2001; Havlin and Kissel, 1997; Heenan *et al.*, 1995; Heinze *et al.*, 2010; Hendrix, 1997; Hermle *et al.*, 2008; Hernanz *et al.*, 2002; Hernanz *et al.*, 2009; Hertnanz *et al.*, 2009; Higashi *et al.*, 2014; Hou *et al.*, 2011; Huggins *et al.*, 2007; Hulugalle, 2000; Hussain *et al.*, 1999; Ismail *et al.*, 1994; Jagadamma and Lal, 2010; Jarecki and Lal, 2010; Jarvis, 1996; Jemai *et al.*, 2012; Jemai *et al.*, 2013; Karlen *et al.*, 1998; Karlen *et al.*, 1994; Kruger, 1996; Kumar *et al.*, 2012; Kumar *et al.*, 2014; Kushwaha *et al.*, 2000; Küstermann *et al.*, 2013; Lal, 1998; Lal *et al.*, 1994; Lammerding *et al.*, 2010; Larney *et al.*, 1997; Laudicina *et al.*, 2014; Lavado *et al.*, 1999; Liang *et al.*, 2011; Liang *et al.*, 2007; Lilienfein *et al.*, 2000; Liu *et al.*, 2014; Lopez-Bellido *et al.*, 2009; Lopez-Bellido *et al.*, 2017; Lopez-Fando *et al.*, 2007; Lopez-Fando and Pardo, 2009; Lou *et al.*, 2012; Martin-Lammerding *et al.*, 2013; Martin-Rueda *et al.*, 2007; Martinez *et al.*, 2013; McCarty *et al.*, 1998; McLeod *et al.*, 2013; Melero *et al.*, 2011; Mielke *et al.*, 1986; Mikha *et al.*, 2010; Mikha *et al.*, 2013; Mrabet *et al.*, 2001; Munoz-Romero *et al.*, 2017; Murage *et al.*, 2006; Nyamadzawo *et al.*, 2008; Nyborg *et al.*, 1995; Olson *et al.*, 2005; Packer *et al.*, 1992; Page *et al.*, 2013; Pierce and Fortin, 1997; Plaza-Bonilla *et al.*, 2011; Powlson and Jenkinson, 1982; Prasad *et al.*, 2016; Presley *et al.*, 2011; Puget and Lal, 2005; Quincke *et al.*, 2006; Rasmussen and Albrecht, 1997; Rhoton *et al.*, 1993; Robertson *et al.*, 2015; Ross and Hughes, 1985; Sa *et al.*, 2014; Saffigna *et al.*, 1989; Sainju *et al.*, 2009; Sainju *et al.*, 2005; Sainju *et al.*, 2011; Sainju *et al.*, 2005; Sainju *et al.*, 2008; Sainju *et al.*, 2002; Salinas-Garcia *et al.*, 1997; Salinas-Garcia *et al.*, 2002; Salvo *et al.*, 2010; Schomberg and Jones, 1998; Sheehy *et al.*, 2013; Shi *et al.*, 2011; Shrestha *et al.*, 2015; Shukla *et al.*, 2006; Singh *et al.*, 2015; Six *et al.*, 2000; Sombrero and de Benito, 2010; Steinbach and Alvarez, 2006; Studdert *et al.*, 2017; Studdert *et al.*, 1997; Sun *et al.*, 2011; Taboada *et al.*, 1998; Thomas *et al.*, 2007; Tian *et al.*, 2013; Tivet *et al.*, 2013; Ussiri and Lal, 2009; van Groenigen *et al.*, 2011; VandenBygaart *et al.*, 2002; Varvel and Wilhelm, 2011; Venterea *et al.*, 2006; Viaud *et al.*, 2010; Wander *et al.*, 1998; Wang and Dalal, 2006; Wanniarachchi *et al.*, 1999; Wright and Hons, 2004; Xu *et al.*, 2013; Yang and Kay, 2001; Yang and Wander, 1999; Zhang *et al.*, 2007; Zhang *et al.*, 2017

Reference C stocks can be derived from country-specific data in a Tier 2 approach. Reference values in Tier 1 correspond to non-degraded, unimproved lands under native vegetation, but other reference conditions can also be chosen for Tier 2. In addition, the depth for evaluating soil C stock changes can be different with the Tier 2 method. The effect of tillage on soil carbon stocks can be markedly different for depths above the tillage depth compared to below the tillage depth (Angers et al. 1997; Angers and Eriksen-Hamel, 2008; Gal et al. 2017), and including soil C stock data below the depth of tillage is necessary to provide an accurate estimate of tillage system effect on C stocks. However, the depth of the reference C stocks (SOC_{REF}) and stock change factors need to the same for all land uses (i.e., F_{LU}, F_I, and F_{MG}) to ensure consistent application of methods for determining the impact of land use change on soil C stocks..

The carbon stock estimates may be improved when deriving country-specific factors for F_{LU} and F_{MG}, by expressing carbon stocks on a soil-mass equivalent basis rather than a soil-volume equivalent (i.e. fixed depth) basis. This is because the soil mass in a certain soil depth changes with the various operations associated with land use that affect the density of the soil, such as uprooting, land levelling, tillage, and rain compaction due to the disappearance of the cover of tree canopy. However, it is important to realize that all soil C stocks used to derive stock change factors across all land uses must be on an equivalent mass basis if this method is applied. This will require necessary soils data to do comprehensively for all land uses. See Box 2.2b in Chapter 2, Section 2.3.3.1 for more information.

Biochar C Amendments

The parameter F_{perm_p} can be based on H/Corg or O/Corg measured directly from representative samples of biochar, or from published data for biochar produced using similar process conditions as the biochar that is applied to soils in the country. Tier 2 emission factors may be disaggregated based on variation in environmental conditions, such as the climate and soil types, in addition to variation associated with the biochar production methods that generate production types defined by the specific feedstock type and conversion process. See Section 2.3.3.1, Chapter 2, Volume IV for more information.

Steady-State Method

Default parameters are provided for the three-pool steady-state C pool equations (Table 5.5a). The average lignin and nitrogen contents of the C input is also required to estimate the size of the three C pools (See Tables 5.5b and 5.5c).

Tier 3

Constant stock change rate factors *per se* are less likely to be estimated in favor of variable rates that more accurately capture land-use and management effects. Tier 3 methods for biochar C amendments to soils are country-specific and may involve empirical or process-based models to account for a broader set of impacts of biochar amendments. More information on Tier 3 methods is provided in Section 2.3.3.1, Chapter 2, Volume IV.

TABLE 5.5A (NEW)
GLOBALLY CALIBRATED MODEL PARAMETERS TO BE USED TO ESTIMATE SOC CHANGES FOR MINERAL SOILS WITH THE TIER 2 STEADY-STATE METHOD

Parameter	Practice	Value (min, max)	Standard Deviation	Description
$till_{fac}$	Full-till	3.036 (1.4, 4.0)	0.579	Tillage disturbance modifier for decay rates
	Reduced-till	2.075 (1.0, 3.0)	0.569	
	No-till	1		
w_s	All	1.331 (0.8, 2.0)	0.386	slope parameter for $mappet_i$ term to estimate w_{fac}
k_{fac_a}	All	7.4	n/a	Decay rate constant under optimal conditions for decomposition of the active sub-pool
k_{fac_s}	All	0.209 (0.058, 0.3)	0.566	Decay rate constant under optimal conditions for decomposition of the slow sub-pool
k_{fac_p}	All	0.00689 (0.005, 0.01)	0.00125	Decay rate constant under optimal conditions for decomposition of the passive sub-pool
f_1	All	0.378 (0.01, 0.8)	0.0719	Fraction of metabolic dead organic matter decay products transferred to the active sub-pool
f_2	Full-till	0.368 (0.007, 0.5)	0.0998	Fraction of structural dead organic matter decay products transferred the active sub-pool
f_3	All	0.455 (0.1, 0.8)	0.201	Fraction of structural dead organic matter decay products transferred to the slow sub-pool
f_5	All	0.0855 (0.037, 0.1)	0.0122	Fraction of active sub-pool decay products transferred to the passive sub-pool
f_6	All	0.0504 (0.02, 0.19)	0.0280	Fraction of slow sub-pool decay products transferred to the passive sub-pool
f_7	All	0.42	n/a	Fraction of slow sub-pool decay products transferred to the active sub-pool
f_8	All	0.45	n/a	Fraction of passive sub-pool decay products transferred to the active sub-pool
t_{opt}	All	33.69 (30.7, 35.34)	0.66	Optimum temperature to estimate temperature modifier on decomposition
t_{max}	All	45	n/a	Maximum monthly average temperature for decomposition.

Methods used in the Bayesian calibration process are described in Annex 5A.3.

Source: Campbell et al. 1997; Collins et al. 2000; Dick et al. 1997; Diaz-Zorita et al. 1999; Dimassi et al. 2014; e-RA 2013; Gregorich et al. 1996; Halvorson et al. 1997; Huggins and Fuchs 1997; Janzen et al. 1997; Jenkinson 1990; Jenkinson and Johnston 1977; KBS LTER 2017; Küstermann and Hülsbergen 2013; Maillard et al. 2018; Marchado 2013; Marchado et al. 2008, 2011; Pierce and Fortin 1997; Rasmussen and Smiley 1997; Schultz 1995; Skjemstad et al. 2004; Vanotti et al. 1997; See Annex 5A.3 for more information.

TABLE 5.5B (NEW) DEFAULT VALUES FOR NITROGEN AND LIGNIN CONTENTS IN CROPS FOR THE STEADY-STATE METHOD		
Crops	**N content of residues[1]**	**Lignin content of residues[2]**
Generic value for crops not indicated below	0.0083	0.073
Generic Grains	0.0068	0.074
Winter Wheat	0.0069	0.053
Spring Wheat	0.0070	0.053
Barley	0.0090	0.046
Oats	0.0073	0.047
Maize	0.0063	0.11
Rye[3]	0.008	0.05
Rice[4]	0.007	0.125
Millet[4]	0.007	0.062
Sorghum[3]	0.0065	0.06
Beans and Pulses	0.008	0.075
Soybeans	0.008	0.085
Potatoes and Tubers	0.0169	0.073
Peanuts[4]	0.016	0.086
N-fixing forages	0.0250	0.072
Alfalfa	0.0238	0.072
Non-N-fixing forages	0.0134	0.049
Perennial Grasses	0.0126	0.049
Grass-Clover Mixtures[4]	0.0178	0.061
Non-legume hay	0.0134	0.057

[1] The estimates are in units of g N (g residue)$^{-1}$ on dry weight basis from a biomass-weighted average of aboveground and belowground for each crop based on data in Table 11.1a in Volume IV, Chapter 11 of this report.

[2] Winter wheat, spring wheat, barley, oats, millet, beans and pulses, soybeans, peanuts, values from Equi-Analytical Laboratories (2018); maize, rice, and sorghum from Cornell University (2017); and potatoes and tubers from Zereu et al. (2014).

[3] Simple average of nitrogent content of aboveground and belowground. [4] Nitrogen content of aboveground assumed to represent all residue.

[4] value is an average of N fixing and non-N fixing grasses.

Notes: Uncertainty is assumed to be ±75% for the N content estimates and ±50% for the lignin content estimates, expressed as a 95% confidence intervals.

TABLE 5.5C (NEW)
DEFAULT VALUES FOR CARBON TO NITROGEN RATIOS, NITROGEN, AND LIGNIN CONTENTS IN LIVESTOCK MANURE FOR THE STEADY-STATE METHOD

Livestock Manure Type	C to N ratio of manure	N content of manure (% dry basis)	Lignin content of manure (% dry basis)
Dairy Cattle	16	2.9	13
Beef Cattle	19[1]	2.3[1]	9[1]
Poultry	10[2]	5.1[2]	5[2]
Swine	11[3]	4.1[3]	5[3]
Horses/Mules/Asses	20	1.3	13[4]
Sheep	11	3.3	13[4]

Sources: Chen et al. 2003 for Dairy Cattle, Beef Cattle, Poultry and Swine.
ASAE 2005 for Horses/Mules/Asses.
MWPS 2004; Hébert et al. 1991; Sørensen and Jensen, 1995; Rees and Castle, 2002 for Sheep
[1]Average of Beef and Cattle- Feedlot categories.
[2]Average across four development categories.
[3]Average of Nursery, Grower and Finisher categories.
[4]Average of Beef and Dairy from Chen et al. 2003.
Notes: Uncertainty is assumed to be ± 50% for all of these estimates, expressed as a 95% confidence interval.

Organic soils

No refinement.

The *2013 Supplement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories: Wetlands* provides additional guidance that updates the *2006 IPCC Guidelines for national Greenhouse Gas Inventories*. See section 2.2 of the *2013 Wetlands Supplement* covers Tier 1, 2, and 3 approaches for drained organic soils in cropland.

5.2.3.3 CHOICE OF ACTIVITY DATA

Mineral soils

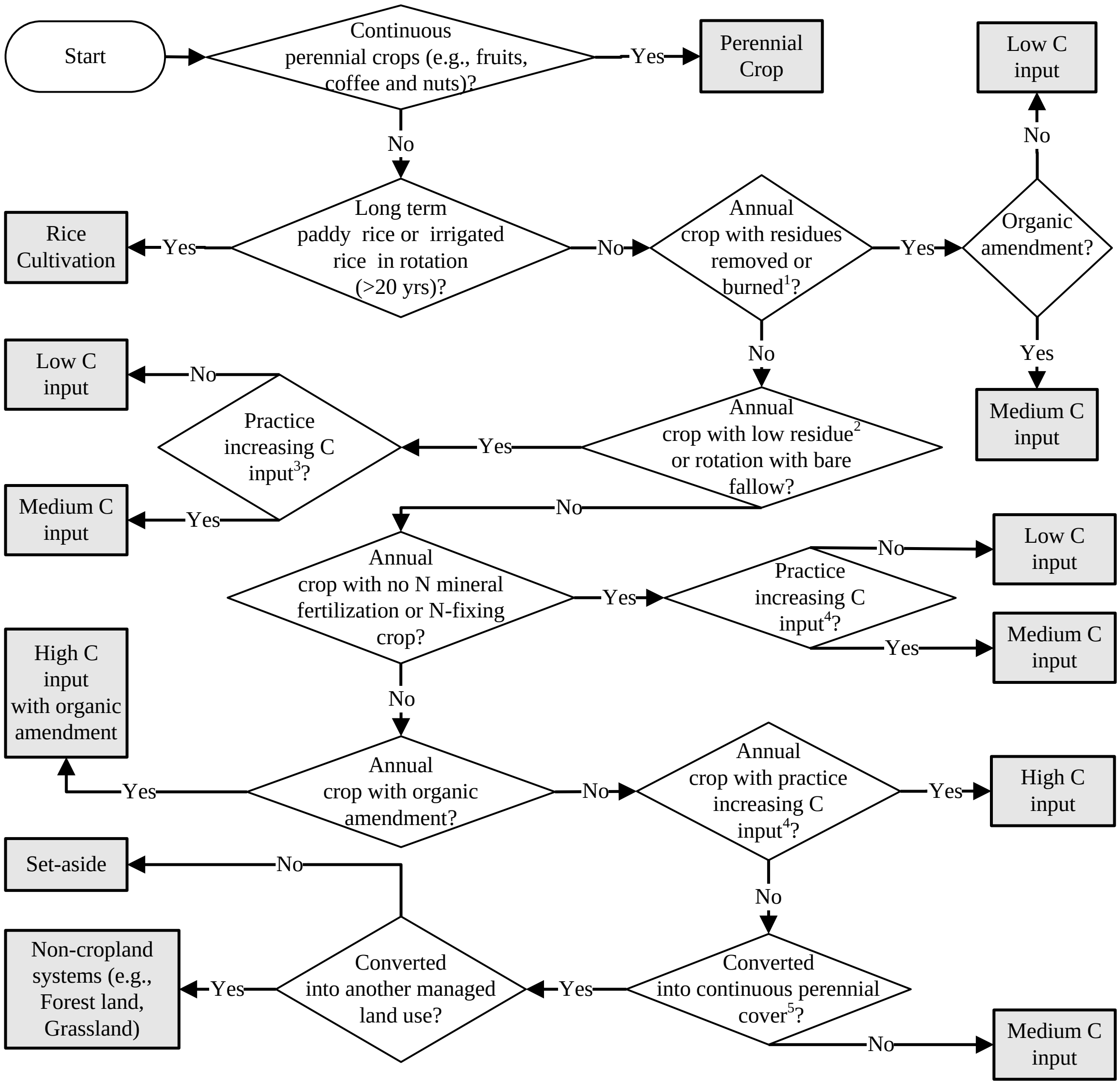
Tier 1

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

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

Figure 5.1 Classification scheme for cropping systems

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



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

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

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

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

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

Tier 2

Developing Country-Specific Factors for the Default Equations

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

For Tier 2, the specific definitions of management and input factors are typically made to match available activity data on how an activity affects C stocks. For example, if a country has management factors related to specific tillage practices that involve a mix of intensities over time, then the country will also need activity data on those specific tillage practices to apply the country-specific factors.

Biochar C Amendments

For biochar C amendments, the activity data required for the Tier 2 method includes the total quantities of biochar distributed as amendment to mineral soils. These data must be disaggregated by production type, where production type is defined as a process utilizing a specific feedstock type, and a specific conversion process. Changes in soil C associated with biochar amendments are considered to occur where it is incorporated into soil. However, due to the distributed nature of the land sector in which this can take place, inventory compilers may not have access to data on when or where biochar C amendments occur. Inventory compilers may be able to compile data on the total amount of biochar applied to cropland mineral soils from biochar producers, exporters, importers, distributors and/or from those applying biochar to cropland in the country. Note that exported biochar is not included in the total amount of biochar amended to soils in the country.

Additionally, activity data on the amount of biochar amendments may be disaggregated by climate zones and/or soil types if country-specific factors are disaggregated by these environmental variables. The additional climate and soil activity data may be obtained with a survey of biochar distributors and land managers.

Steady-State Method

This method requires soil C input data based on the amount of biomass that is converted to dead organic matter annually. This rate will vary depending on the crop production, management activity, and other environmental variables. Removals or reductions in dead organic matter are subtracted from the C input amount, which could occur with livestock grazing, grassland burning, or harvesting of grass for feed or bioenergy. Additions of C, particularly organic amendments such as manure, are included in the estimate of C input.

It is *good practice* to estimate C input using country-specific factors in order to produce more accurate estimates. If country-specific factors are not available, Equation 5.0h can be used to estimate C inputs with global factors provided in Table 11.1a, Chapter 11, Volume 4 or alternatively, the amount can be calculated using the method and data in Table 11.2, Chapter 11.

EQUATION 5.0H (NEW)
CROPLAND C- INPUT TO SOIL FOR THE STEADY-STATE METHOD

$$C_{input} = \sum_{T} \left(AGR_{(T)} \bullet C_{AG(T)} \right) + \left(BGR_{(T)} \bullet C_{BG(T)} \right) + \left(F_{AM(T)} \bullet CN_{AM(T)} \right)$$

$$AGR_{(T)} = AG_{DM(T)} \bullet Area_{(T)} \bullet Frac_{Renew(T)} \bullet \left(1 - Frac_{Removal(T)} - \left(Frac_{Burnt(T)} \bullet C_f \right) \right)$$

$$BGR_{(T)} = Crop_{(T)} \bullet \left(1 + AG_{DM(T)} \right) \bullet RS_{(T)} \bullet Area_{(T)} \bullet Frac_{Renew(T)}$$

$$AG_{DM(T)} = Crop_{(T)} \bullet R_{AG(T)}$$

Where:

C_{input} = annual amount of C input from residues to the soil (above and below ground), kg C yr^{-1}

$AGR_{(T)}$ = annual total amount of above-ground crop residue for crop T, kg d.m. yr^{-1}.

$C_{AG(T)}$ = C content of above-ground residues for crop T, kg C (kg d.m.) $^{-1}$ (Default: 0.42 kg C (kg d.m.) $^{-1}$)

$Frac_{Remove(T)}$ = fraction of above-ground residues of crop T removed annually for purposes such as feed, bedding and construction, dimensionless. Survey of experts in country is required to obtain data. If data for $Frac_{Remove}$ are not available, assume no removal

$Frac_{Burnt(T)}$ = fraction of annual harvested area of crop T burnt, dimensionless

C_f = combustion factor (dimensionless) (refer to Chapter 2, Table 2.6)

$BGR_{(T)}$ = annual total amount of belowground crop residue for crop T, kg d.m. yr^{-1}

$C_{BG(T)}$ = C content of below-ground residues for crop T, kg C (kg d.m.)$^{-1}$, (Default: 0.42 kg C (kg d.m.) $^{-1}$)

$F_{AM(T)}$ = N in animal manures applied to crop T, kg N yr^{-1} (Equation 10.34 in Section 10.5.4, Chapter 10)

$CN_{AM(T)}$ = C to N ratio of animal manures applied to crop T, kg C (kg N)$^{-1}$ (Table 5.5c)

$AG_{DM(T)}$ =Above-ground residue dry matter for crop T, kg d.m. ha^{-1}

(Use factors for $R_{AG(T)}$ in Table 11.1a, Chapter 11, or alternatively, the above-ground residue dry matter may be estimated using the method and data in Table 11.2, Chapter 11)

$Crop_{(T)}$ = harvested annual dry matter yield for crop T, kg d.m. ha^{-1} (Use Equation 11.7, Chapter 11)

$R_{AG(T)}$ = ratio of above-ground residues dry matter ($AG_{DM(T)}$) to harvested yield for crop T ($Crop_{(T)}$), kg d.m. ha^{-1}(kg d.m. ha^{-1})$^{-1}$, (Table 11.1a)

$Area_{(T)}$ = total annual area harvested of crop T, ha yr^{-1}

$Frac_{Renew(T)}$ = fraction of total area under crop T that is renewed annually [8], dimensionless. For countries where forages are renewed on average every X years, $Frac_{Renew(T)}$ = 1/X. For annual crops $Frac_{Renew(T)}$ = 1

$RS_{(T)}$ = ratio of below-ground root biomass to above-ground shoot biomass for crop T, kg d.m. ha^{-1} (kg d.m. $ha^{-1})^{-1}$, (Table 11.1a)

T = crop or forage type

Data on crop yield statistics (yields and area harvested, by crop) may be obtained from national sources. If such data are not available, FAO publishes data on crop production: (http://faostat.fao.org/). Tillage management data are also required (proportion of full tillage, reduced tillage and no-till), and irrigation data for any lands that are provided supplement water (proportion of land). Monthly average temperature, precipitation and potential evapotranspiration is needed for each grid cell or region. This information is available from global datasets, such as the CRU climate dataset (https://crudata.uea.ac.uk/cru/data/hrg/), if country-specific data are not available. The average sand content is needed for each grid cell or region, which is available from Harmonized World Soil Database (http://webarchive.iiasa.ac.at/Research/LUC/External-World-soil-database/HTML/).

Tier 3

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

For biochar C amendments, the additional activity data required to support a Tier 3 method will depend on which processes are represented and which environmental variables that are required as input to the model. Priming effects, soil GHG emissions, and plant production responses to biochar all vary with biochar type, climate, and soil type. Furthermore, soil GHG emissions and plant production responses also vary with crop type and management. Therefore, Tier 3 methods may require environmental data on climate zones, soil types, crop types and crop management systems (such as nitrogen fertilizer application rates, and whether soils are flooded for paddy rice production), in addition to the amount of biochar amendments in each of the individual combinations of strata for the environmental variables. More detailed activity data specifying the process conditions for biochar production or the physical and chemical characteristics of the biochar may also be required (such as surface area, cation exchange capacity, pH, and ash content).

Organic soils

No refinement.

The *2013 Supplement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories: Wetlands* provides additional guidance that updates the *2006 IPCC Guidelines for national Greenhouse Gas Inventories*. See section 2.2 of the *2013 Wetlands Supplement covers Tier 1, 2, and 3 approaches for drained organic soils in cropland.*

5.2.3.4 CALCULATION STEPS FOR TIER 1

Mineral soils

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

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

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

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

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

[8] This term is included in the equation to account for N release and the subsequent increases in N_2O emissions (e.g., van der Weerden *et al.*, 1999; Davies *et al.*, 2001), from renewal/cultivation of grazed grass or grass/clover pasture and other forage crops.

Step 5: Assign a land-use factor (F_{LU}), management factor (F_{MG}) and C input levels (F_I) to each Cropland based on the management classification (Step 2). Values for F_{LU}, F_{MG} and F_I are given in Table 5.6.

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

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

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

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

A numerical example is given below for *Cropland Remaining Cropland* on mineral soils, using Equation 2.25 and default reference C stocks (Table 2.3) and stock change factors (Table 5.6).

Example: The following example shows calculations for aggregate areas of cropland soil carbon stock change. In a warm temperate wet climate on high activity clay soils there are 1Mha of permanent annual cropland. The native reference carbon stock (SOC_{REF}) for the region is 64 tonnes C ha^{-1}. At the beginning of the inventory calculation period (in this example, 10 yrs earlier in 1990), the distribution of cropland systems were 400,000 ha of annual cropland with low carbon input levels and full tillage and 600,000 ha of annual cropland with medium input levels and full tillage. Thus, initial soil carbon stocks for the area were:

400,000 ha ● (64 tonnes C ha^{-1} ● 0.75 ● 1 ● 0.92) + 600,000 ha ● (64 tonnes C ha^{-1} ● 0.75 ● 1 ● 1) = 46.46 million tonnes C.

In the last year of the inventory time period (in this example, the last year is 2000), there are: 200,000 ha of annual cropping with full tillage and low C input, 700,000 ha of annual cropping with reduced tillage and medium C input, and 100,000 ha of annual cropping with no-till and medium C input. Thus, total soil carbon stocks based on the inventory year are:

200,000 ha ● (64 tonnes C ha^{-1} ● 0.75 ● 1 ● 0.92) + 700,000 ha ● (64 tonnes C ha^{-1} ● 0.75 ● 1.01 ● 1) + 100,000 ha ● (64 tonnes C ha^{-1} ● 0.75 ● 1.11 ● 1) = 49.06 million tonnes C.

Thus, the average annual stock change over the period for the entire area is: 49;06 – 46.46 = 2.60 million tonnes/20 yr = 130000 tonnes C per year soil C stock increase (Note: 20 years is the time dependence of the stock change factor, i.e., factor represents annual rate of change over 20 years).

Organic soils

No refinement.

The *2013 Supplement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories: Wetlands* provides additional guidance that updates the *2006 IPCC Guidelines for national Greenhouse Gas Inventories*. See section 2.2 of the *2013 Wetlands Supplement covers Tier 1, 2, and 3 approaches for drained organic soils in cropland.*

5.2.3.5 UNCERTAINTY ASSESSMENT

No refinement.

5.2.4 Non-CO_2 greenhouse gas emissions from biomass burning

No refinement.

5.3 LAND CONVERTED TO CROPLAND

No refinement in the Introduction.

5.3.1 Biomass

5.3.1.1 CHOICE OF METHOD

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

It is *good practice* to consider all carbon pools (i.e., above ground and below ground biomass, dead organic matter, and soils) in estimating changes in carbon stocks in *Land Converted to Cropland*. Currently, there is insufficient information to provide a default approach with default parameters to estimate carbon stock change in dead organic matter (DOM) pools[9]. DOM is unlikely to be important except in the year of conversion. It is assumed that there will be no DOM in Cropland. In addition, the methodology below considers only carbon stock change in above-ground biomass since limited data are available on below-ground carbon stocks in perennial Cropland.

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

Tier 1

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

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

As described in section 5.3.1.1., at Tier 1, carbon stocks in biomass immediately after conversion (B_{AFTER}) are assumed to be zero, since the land is cleared of all vegetation before planting crops. Average carbon stock change per hectare for a given land-use conversion is multiplied by the estimated area of lands undergoing such a conversion in a given year. In subsequent years, change in biomass of annual crops is considered zero because carbon gains in biomass from annual growth are offset by losses from harvesting. Changes in biomass of perennial woody crops are counted following the methodology in Section 2.3.1.1 (Change in carbon stocks in biomass in

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

land remaining in a land-use category) and Section 5.2.1 (Change in carbon stocks in biomass in cropland remaining cropland). Thus, carbon gain of an annual crop is estimated only for the first year following a conversion, whereas, carbon gains and losses of perennial woody crop may also occur in subsequent years up to 20 years (at maximum).

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

Tier 2

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

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

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

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

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

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

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

Impossible transitions are blacked out.

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

Tier 3

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

5.3.1.2 CHOICE OF EMISSION FACTORS

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

Tier 1

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

In addition, a value is needed for carbon stocks after one year of growth in crops planted after conversion (ΔC_G). Updated Table 5.9 provides general defaults for annual and perennial crop for ΔC_G while updated Table 5.3 provides defaults for specific perennial crops. Separate defaults are provided for annual non-woody crops and perennial woody crops. For lands planted in annual crops, the default value of ΔC_G is 4.7 tonnes of C per hectare, based on the original *IPCC Guidelines* recommendation of 10 tonnes of dry biomass per hectare (dry biomass has been converted to tonnes carbon in Table 5.9). The total accumulation of carbon in perennial woody biomass will, over time, exceed that of the default carbon stock for annual cropland. However, default values provided in this section are for one year of growth immediately following conversion, which usually give lower carbon stocks for perennial woody crops compared to annual crops.

TABLE 5.8 (UPDATED[1]).
DEFAULT BIOMASS CARBON STOCKS REMOVED DUE TO LAND CONVERSION TO CROPLAND

Land-use category	Carbon stock in biomass* before conversion (B_{Before}) (tonnes C ha^{-1})	Error range #
Forest Land	See Chapter 4 Tables 4.7 to 4.12 for carbon stocks in a range of forest types by climate regions. Stocks are in terms of dry matter. Multiply values by a carbon fraction (CF) in Table 4.3 consistent with what used in forest land estimation to convert dry matter to carbon.	See Section 4.3 (Land Converted to Forest Land)
Grassland	See Chapter 6 Table 6.4 for carbon stocks in a range of grassland types by climate regions. Multiply default carbon fraction (CF) 0.47 (for herbaceous biomass for Grassland, see page 6.29, Chapter 6 of the *2006 IPCC Guidelines* to convert dry matter to carbon.	± 75%

1 Updates Table 5.8 from the IPCC *2006 IPCC Guidelines*.

* Note that the condition of forests that are converted to grassland or cropland is not likely to be typical of the forest type in general, i.e. the carbon stocks are probably lower than average (Carter et al. 2017; Puhlick et al 2017). Specific values for disturbed forest may be appropriate.

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

TABLE 5.9 (UPDATED[1])
DEFAULT BIOMASS CARBON STOCKS PRESENT ON LAND CONVERTED TO CROPLAND IN THE YEAR FOLLOWING CONVERSION

Crop type by climate region	Ecological zone	Continent	Cropping system	Carbon stock in biomass after one year (ΔC_G) (tonnes C ha^{-1})	Error range#
Annual cropland	All	All	Annual cropland	4.7	± 75%
Perennial cropland	All	All	Agroforestry	See G in Tables 5.1 and 5.2	
	All	All	Monocultures	See G in Table 5.3	

[1] Update to Table 5.9 in the *2006 IPCC Guidelines*

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

Tier 2

Tier 2 methods should include some country-specific estimates for biomass stocks and removals due to land conversion, and also include estimates of on-site and off-site losses due to burning and decay following land conversion to Cropland. These improvements can take the form of systematic studies of carbon content and emissions and removals associated with land uses and land-use conversions within the country and a re-examination of default assumptions in light of country-specific conditions. In general, the condition of forests that are converted to grassland or cropland is not likely to be typical of the forest type, i.e. the carbon stocks are probably lower than average. It is *good practice* for countries to evaluate country specific values for disturbed forest under Tier 2.

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

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

Tier 3

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

5.3.1.3 CHOICE OF ACTIVITY DATA

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

Tier 1

Separate estimates are required of areas converted to Cropland from initial land uses (i.e., Forest Land, Grassland, Settlements, etc.) to final crop land type (i.e., annual or perennial) (A_{TO_OTHERS}). For example, countries should estimate separately the area of tropical moist forest converted to annual cropland, tropical moist forest converted to perennial cropland, tropical moist Grassland converted to perennial cropland, etc. Although, to allow other pools to equilibrate and for consistency with land area estimation overall, land areas should remain in the conversion category for 20 years (or other period reflecting national circumstances) following conversion. The methodology assumes that area estimates are based on a one-year time frame, which is likely to require estimation on the basis of average rates on land-use conversion, determined by measurements estimates made at longer intervals. If countries do not have these data, partial samples may be extrapolated to the entire land base or historic estimates of conversions may be extrapolated over time based on the judgement of country experts. Under Tier 1 calculations, international statistics such as FAO databases, *GPG-LULUCF* 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. For perennial woody cropland, the total area of planted perennial woody crops for the age classes within the maturing/harvesting cycle (up to 20 years) is required to estimate all biomass carbon change (ΔC_G). See section 5.2.1.3 for details.

Tier 2

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

Tier 3

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

5.3.1.4 CALCULATION STEPS FOR TIER 1 AND TIER 2

No refinement.

5.3.1.5 UNCERTAINTY ASSESSMENT

No refinement.

5.3.2 Dead organic matter

No refinement.

5.3.3 Soil carbon

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

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

To account for changes in soil C stocks associated with *Land Converted to Cropland*, countries need to have, at a minimum, estimates of the areas of *Land Converted to Cropland* during the inventory time period. If land-use and management data are limited, aggregate data, such as FAO statistics, can be used as a starting point, along with knowledge of country experts of the approximate distribution of land-use types being converted and their associated management. If the previous land uses and conversions are unknown, SOC stocks changes can still be computed using the methods provided in *Cropland Remaining Cropland*, but the land base area will likely be different for croplands in the current year relative to the initial year in the inventory. It is critical, however, that the total land area across all land-use sectors be equal over the inventory time period (e.g., 7 million ha may be converted from Forest Land and Grassland to Cropland during the inventory time period, meaning that croplands will have an additional 7 Million ha in the last year of the inventory, while grasslands and forests will have a corresponding loss of 7 Million ha in the last year). *Land Converted to Cropland* is stratified according to climate regions and major soil types, which could either be based on default or country-specific classifications. This can be accomplished with overlays of climate and soil maps, coupled with spatially-explicit data on the location of land conversions.

5.3.3.1 CHOICE OF METHOD

Inventories can be developed using a Tier 1, 2 or 3 approach with each successive tier requiring more detail and resources than the previous one. It is also possible that countries will use different tiers to prepare estimates for the separate subcategories of soil C (i.e., soil organic C stocks changes in mineral soils and organic soils; and stock changes associated with soil inorganic C pools). Decision trees are provided for mineral soils (Figure 2.5) and organic soils (Figure 2.6) in Section 2.3.3.1 (Chapter 2) to assist inventory compilers with selection of the appropriate tier for their soil C inventory.

Mineral soils

Tier 1

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

Tier 2

The Tier 2 method for mineral soils also uses Equation 2.25, but involves country-specific or region-specific reference C stocks and/or stock change factors and may include disaggregated land-use activity and environmental data. Tier 2 methods for biochar C amendments utilize a top-down approach in which the total amount of biochar generated and added to mineral soil is used to estimate the change in soil organic C stocks with country-specific factors. See Section 2.3.3.1, Chapter 2, Volume IV for more information.

Tier 3

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

Tier 3 methods for biochar C amendments can be used to address GHG sources and sinks not captured in Tiers 1 or 2, such as priming effects, changes to N_2O or CH_4 fluxes from soils, and changes to net primary production. More information on Tier 3 methods is provided in Section 2.3.3.1 of Chapter 2, Volume IV.

Organic soils

No refinement.

The *2013 Supplement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories: Wetlands* provides additional guidance that updates the *2006 IPCC Guidelines for national Greenhouse Gas Inventories*. See section 2.2 of the *2013 Wetlands Supplement* covers Tier 1, 2, and 3 approaches for drained organic soils in cropland.

5.3.3.2 CHOICE OF STOCK CHANGE AND EMISSION FACTORS

Mineral soils

Tier 1

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

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

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

Factor value type	Level	Climate regime	IPCC default	Error #	Definition

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

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

Tier 2

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

Reference C stocks can be derived from country-specific data in a Tier 2 approach. Reference values in Tier 1 correspond to non-degraded, unimproved lands under native vegetation, but other reference conditions can also be chosen for Tier 2. In addition, the depth for evaluating soil C stock changes can be different with the Tier 2 method (see also section 6.2.3.1). However, the depth of the reference C stocks (SOC_{REF}) and stock change factors needs to be the same for all land uses (i.e., F_{LU}, F_I, and F_{MG}) to ensure consistency in the application of methods for estimating the impact of land use change on soil C stocks.

The Tier 1 method may over- or under-estimate soil C stock changes on an annual basis, particularly with land use change (e.g., Villarino et al., 2014). Therefore, land use change, such as *Cropland converted to Grassland*, may include development of factors that estimate changes over longer periods of time than the default 20 years, and may better match the period of time over which carbon accumulates or is lost from soils due to land use change. When C stock changes extend over periods of many decades, activity data for historical land-use change are needed to estimate the soil C stock changes that are still occurring in the current inventory year.

The carbon stock estimates may be improved when deriving country-specific factors for F_{LU} and F_{MG}, by expressing carbon stocks on a soil-mass equivalent basis rather than a soil-volume equivalent (i.e. fixed depth) basis. This is because the soil mass in a certain soil depth changes with the various operations associated with land use that affect the density of the soil, such as uprooting, land levelling, tillage, and rain compaction due to the disappearance of the cover of tree canopy. However, it is important to realize that all data used to derive stock change factors across all land uses must be on an equivalent mass basis if this method is applied. This will be challenging to do comprehensively for all land uses. See Box 2.2b in Chapter 2, Section 2.3.3.1 for more information.

For biochar C amendments, the parameter F_{perm_p} can be based on H/Corg or O/Corg measured directly from representative samples of biochar, or from published data for biochar produced using similar process conditions as the biochar that is applied to soils in the country. Tier 2 emission factors may be disaggregated based on variation in environmental conditions, such as the climate and soil types, in addition to variation associated with the biochar production methods that generate production types defined by the feedstock type and conversion process. See Section 2.3.3.1, Chapter 2, Volume IV for more information.

Country-specific emission factors (i.e., permanence factors) for biochar C for croplands may be different from the past land use for *Land Converted to Cropland*, and these differences need to be addressed in the calculations. This requires estimating the biochar carbon stocks from past biochar carbon additions that remain in *Land Converted to Cropland* after conversion. The biochar C stocks are then subject to the conditions for cropland, which may lead some additional loss of biochar C.

Tier 3

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

Tier 3 methods for biochar C amendments are country-specific and may involve empirical or process-based models to account for a broader set of impacts of biochar amendments. These methods will likely estimate biochar C stocks and associated changes over time so the biochar C stocks in Land Converted to Cropland will need to be tracked through the land use change process.

More information on Tier 3 methods is provided in Section 2.3.3.1, Chapter 2, Volume IV.

Organic soils

No refinement.

The *2013 Supplement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories: Wetlands* provides additional guidance that updates the *2006 IPCC Guidelines for national Greenhouse Gas Inventories*. See section 2.2 of the *2013 Wetlands Supplement* covers Tier 1, 2, and 3 approaches for drained organic soils in cropland.

5.3.3.3 CHOICE OF ACTIVITY DATA

Mineral soils

Tier 1 and Tier 2 - Default Equations

For purposes of estimating soil carbon stock change, area estimates of *Land Converted to Cropland* should be stratified according to major climate regions and soil types. This can be based on overlays with suitable climate and soil maps and spatially-explicit data of the location of land conversions. Detailed descriptions of the default climate and soil classification schemes are provided in Chapter 3, Annex 3A.5. Specific information is provided in the each of the land-use chapters regarding treatment of land-use/management activity data (Forest Land in Section 4.2.3.3, Cropland in 5.2.3.3, Grassland in 6.2.3.3, Settlements in 8.2.3.3, and Other Land in 9.3.3.3).

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

For biochar C amendments, the activity data for the Tier 2 method includes the total quantities of biochar distributed as amendment to mineral soils. These data must be disaggregated by production type, where production type is defined as a process utilizing a specific feedstock type, and a specific conversion process. Changes in soil C associated with biochar amendments are considered to occur where it is incorporated into soil. However, due to the distributed nature of the land sector in which this can take place, inventory compilers may not have access to data on when or where biochar C amendments occur. Inventory compilers may be able to compile data on the total amount of biochar applied to cropland mineral soils from biochar producers, distributors and/or from those applying biochar to cropland in the country. Note that exported biochar is not included in the total amount of biochar amended to soils in the country.

Additionally, activity data on the amount of biochar amendments may be disaggregated by climate zones and/or soil types if country-specific factors are disaggregated by these environmental variables. The additional climate and soil activity data may be obtained with a survey of biochar distributors and land managers.

Tier 3

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

For biochar C, the additional activity data required to support a Tier 3 method will depend on which processes are represented and environmental variables that are required as input to the model. Priming effects, soil GHG emissions, and plant production responses to biochar all vary with biochar type, climate, and soil type. Furthermore, soil GHG emissions and plant production responses also vary with crop type and management. Therefore, Tier 3 methods may require environmental data on climate zones, soil types, crop types and crop management systems (such as nitrogen fertilizer application rates, and whether soils are flooded for paddy rice production), in addition to the amount of biochar amendments in each of the individual combinations of strata for the environmental variables. More detailed activity data specifying the process conditions for biochar production or the physical and chemical characteristics of the biochar may also be required (such as surface area, cation exchange capacity, pH, and ash content).

Organic soils

No Refinement.

The *2013 Supplement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories: Wetlands* provides additional guidance that updates the *2006 IPCC Guidelines for national Greenhouse Gas Inventories*. See section 2.2 of the *2013 Wetlands Supplement* covers Tier 1, 2, and 3 approaches for drained organic soils in cropland.

5.3.3.4 CALCULATION STEPS FOR TIER 1

Mineral soils

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

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

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

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

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

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

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

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

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

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

A numerical example is given below for Forest Land converted to Cropland on mineral soils, using Equation 2.25 and default reference C stocks (Table 2.3) and stock change factors (Table 5.6).

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} ● 0.90 ● 1 ● 0.92 = 58.0 tonnes C ha^{-1}.

Thus the average annual change in soil C stock for the area over the inventory time period is calculated as:

(58 tonnes C ha^{-1} – 70 tonnes C ha^{-1}) / 20 yrs = -0.6 tonnes C ha^{-1} yr^{-1}.

Organic soils

No refinement.

The *2013 Supplement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories: Wetlands* provides additional guidance that updates the *2006 IPCC Guidelines for national Greenhouse Gas Inventories*. See section 2.2 of the *2013 Wetlands Supplement* covers Tier 1, 2, and 3 approaches for drained organic soils in cropland.

5.3.3.5 UNCERTAINTY ASSESSMENT

No refinement.

5.3.4 Non-CO_2 greenhouse gas emissions from biomass burning

No refinement.

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

No refinement.

5.5 METHANE EMISSIONS FROM RICE CULTIVATION

No refinement in the Introduction.

5.5.1 Choice of method

The basic equation to estimate CH_4 emissions from rice cultivation is shown in Equation 5.2. CH_4 emissions are estimated by multiplying daily emission factors by cultivation period[10] of rice and annual harvested areas[11]. In its most simple form, this equation is implemented using national activity data (i.e., national average cultivation period of rice and area harvested) and a single emission factor. However, the natural conditions and agricultural management of rice production may be highly variable within a country. It is *good practice* to account for this variability by disaggregating national total harvested area into sub-units (e.g., harvested areas under different water regimes). Harvested area for each sub-unit is multiplied by the respective cultivation period and emission factor that is representative of the conditions that define the sub-unit (Sass, 2002). With this disaggregated approach, total annual emissions are equal to the sum of emissions from each sub-unit of harvested area.

EQUATION 5.1
CH_4 EMISSIONS FROM RICE CULTIVATION

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

Where:

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

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

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

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

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

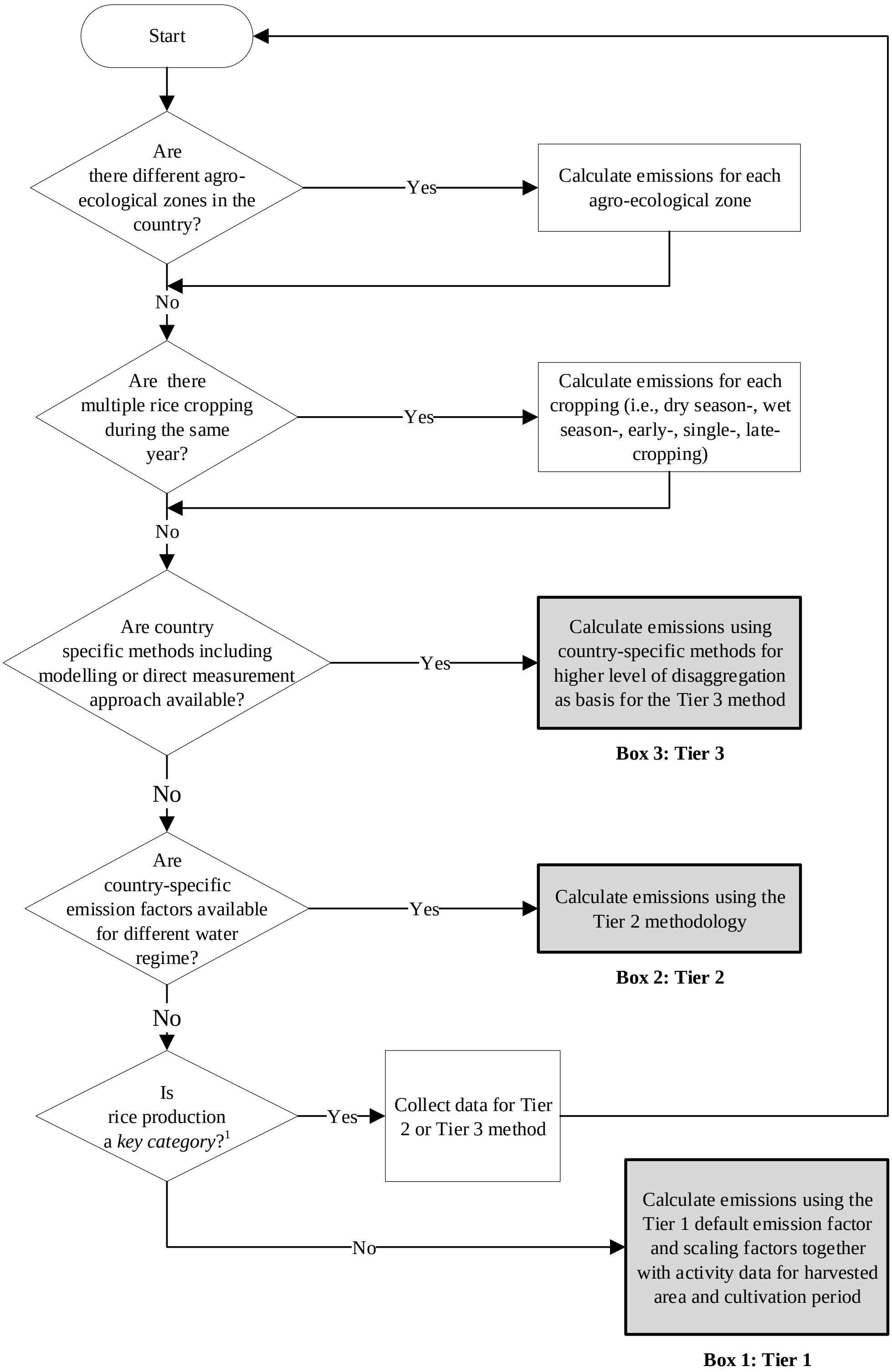
The different conditions that should be considered include rice ecosystem types, flooding pattern before and during cultivation period, and type and amount of organic amendments. Other conditions such as soil type, and rice cultivar can be considered for the disaggregation if country-specific information about the relationship between these conditions and CH_4 emissions are available. The rice ecosystem types and water regimes during cultivation period are listed in Table 5.12. If the national rice production can be sub-divided into agro-climatic zones with different production systems)e.g., flooding patterns(, Equation 5.2 should be applied to each region separately. The same applies if rice statistics or expert judgments are available to distinguish management practices or other factors along administrative units (district or province(. In addition, if more than one crop is harvested during a given year, emissions should be estimated for each cropping season taking into account possible differences in cultivation practices (e.g., use of organic amendments, flooding pattern before and during the cultivation period).

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

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

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

Figure 5.2 Decision tree for CH_4 emissions from rice production



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

Tier 1

Tier 1 applies to countries in which either CH_4 emissions from rice cultivation are not a *key category* or country-specific emission factors do not exist. The disaggregation of the annual harvest area of rice needs to be done for at least three baseline water regimes including irrigated, rainfed, and upland. It is encouraged to incorporate as many of the conditions (*i*, *j*, *k*, etc.) that influence CH_4 emissions (summarized in Box 5.2) as possible. Emissions for each sub-unit are adjusted by multiplying a baseline default emission factor (for field with no pre-season flooding for less than 180 days prior to rice cultivation and continuously flooded fields without organic amendments, EF_c) by various scaling factors as shown in Equation 5.2. The calculations are carried out for each water regime and organic amendment separately as shown in Equation 5.3.

EQUATION 5.2 (UPDATED)
ADJUSTED DAILY EMISSION FACTOR (TIER 1)

$$EF_i = EF_c \bullet SF_w \bullet SF_p \bullet SF_o$$

Where:

EF_i = adjusted daily emission factor for a particular harvested area

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

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

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

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

Tier 2

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

EQUATION 5.2A (NEW)
ADJUSTED DAILY EMISSION FACTOR (TIER 2)

$$EF_i = EF_c \bullet SF_w \bullet SF_p \bullet SF_o \bullet SF_s \bullet SF_r$$

Where:

SF_s = scaling factor for soil type

SF_r = scaling factor for rice cultivar

Tier 3

Tier 3 includes models and monitoring networks tailored to address national circumstances of rice cultivation, repeated over time, driven by high-resolution activity data (e.g. satellite-based and in-situ measurement) and disaggregated at sub-national level. Models can be empirical or mechanistic, but in either case need to be validated with independent observations from country or region-specific studies (Cai *et al*., 2003b; Li *et al*., 2004; Huang *et al*., 2004; and Pathak *et al*., 2005). Tier 3 methodologies may also take into account inter-annual variability triggered by typhoon, flooding, drought, etc. A few countries have used Tier 3 method in their national communications to UNFCCC[12] [e.g. China and Japan used CH_4MOD (Huang *et al*., 2004) and DNDC-Rice models (Katayanagi *et al*., 2017), and USA used DayCent (Cheng et al. 2013)].

[12] https://unfccc.int/

BOX 5.2 (UPDATED)
CONDITIONS INFLUENCING CH_4 EMISSIONS FROM RICE CULTIVATION

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

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

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

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

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

Flooding pattern: Flooding pattern of rice fields has a significant effect on CH_4 emissions (Sass et al., 1992; Yagi et al., 1996; Wassmann et al., 2000; Pathak and Wassmann, 2007; Pathak et al., 2003). Rice ecosystems can further be distinguished into continuously and intermittently flooded (irrigated rice), and regular rainfed, drought prone, and deep water (rainfed), according to the flooding patterns during the cultivation period. Also, flooding pattern before cultivation period should be considered (Yagi et al., 1998; Cai et al., 2000; 2003a; Fitzgerald et al., 2000).

Organic amendments to soils: Organic material incorporated into rice soils increases CH_4 emissions (Schütz et al., 1989; Yagi and Minami, 1990; Sass et al., 1991; Pathak and Wassmann, 2007; Pathak et al., 2003). The impact of organic amendments on CH_4 emissions depends on type and amount of the applied material which can be described by a dose response curve (Denier van der Gon and Neue, 1995; Yan et al., 2005). Organic material incorporated into the soil can either be of endogenous (straw, green manure, etc.) or exogenous origin (compost, farmyard manure, etc.). Calculations of emissions should consider the effect of organic amendments.

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

5.5.2 Choice of emission and scaling factors

Tier 1

Scaling factors are used to adjust the baseline emission factor (EF_c), as provided in Table 5.11, to account for the various conditions discussed in Box 5.2, which result in adjusted daily emission factors (EF_i) for a particular sub-unit of disaggregated harvested area according to Equation 5.3. Default cultivation period is provided in Table 5.11A which can be used for Equation 5.1.

The most important scaling factors, namely water regime during and before cultivation period and organic amendments, are represented in Tables 5.12, 5.13 and 5.14, respectively, through default values. Country-specific scaling factors should only be used if they are based on well-researched and documented measurement data. It is encouraged to consider soil type, rice cultivar, and other factors, if available.

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

World		Regional		
Emission factor ($kg\ CH_4\ ha^{-1}\ d^{-1}$)	**Error range ($kg\ CH_4\ ha^{-1}\ d^{-1}$)**	**Region**	**Emission factor ($kg\ CH_4\ ha^{-1}\ d^{-1}$)**	**Error range ($kg\ CH_4\ ha^{-1}\ d^{-1}$)**
1.19	0.80 – 1.76	Africa [1]	1.19	0.80 – 1.76
		East Asia	1.32	0.89 – 1.96
		Southeast Asia	1.22	0.83 – 1.81
		South Asia	0.85	0.58 – 1.26
		Europe	1.56	1.06 – 2.31
		North America	0.65	0.44 – 0.96
		South America	1.27	0.86 – 1.88

Note: Emission factors and error ranges were estimated based on 95% confidence interval, using statistical model with updated database; See Annex 5A.2 for more information.

[1] For Africa, the global estimate is used due to lack of data.

TABLE 5.11A (NEW)
DEFAULT CULTIVATION PERIOD OF RICE

World		Regional		
Cultivation Period (day)	**Error range (day)**	**Region**	**Cultivation Period (day)**	**Error Range (day)**
113	74– 152	Africa [1]	113	74 – 152
		East Asia	112	73 – 147
		Southeast Asia	102	78 – 150
		South Asia	112	90 – 140
		Europe	123	111 – 153
		North America	139	110 – 165
		South America	124	110 – 146

Note: Cultivation period was calculated from updated database, and the error range or uncertainty was based on the 2.5th percentile to 97.5th percentile of the distribution of ratios; See Annex 5A.2 for more information.

[1] For Africa, the global estimate is used due to lack of data.

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

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

Water regime		Aggregated case		Disaggregated case	
		Scaling factor)SFw(	Error range	Scaling factor)SFw(	Error range
Upland [a]		0	-	0	–
Irrigated [b]	Continuously flooded	0.60	0.44 – 0.78	1.00	0.73 – 1.27
	Single drainage period			0.71	0.53 – 0.94
	Multiple drainage periods			0.55	0.41 – 0.72
Rainfed and deep water [c]	Regular rainfed	0.45	0.32 – 0.62	0.54	0.39 – 0.74
	Drought prone			0.16	0.11 – 0.24
	Deep water	0.06	0.03 – 0.12	0.06	0.03 – 0.12

Source: Scaling factors and error ranges (based on 95% confidential interval) were determined using statistical model and updated database; see Annex 5A.2 for more information.

Notes:

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

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

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

• Single drainage period: Fields have a single drainage event and period during the cropping season at any growth stage, in addition to the end of season drainage.

• Multiple drainage periods: Fields have more than one drainage event and period of time without flooded conditions during the cropping season, in addition to an end of season drainage, including alternate wetting and drying (AWD).

[c] Fields are flooded for a significant period of time with water regimes that depend solely on precipitation.

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

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

• Deep-water rice: Water level rises to more than 50 cm above the soil for a significant period of time during the cropping season.

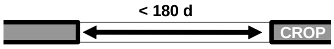
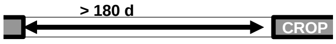
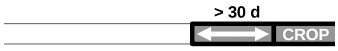
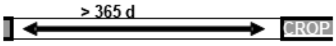
Other rice ecosystem categories, like swamps and inland, saline or tidal wetlands may be discriminated within each sub-category.

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

1. Non-flooded pre-season < 180 days, which often occurs under double cropping of rice;
2. Non-flooded pre-season > 180 days, e.g., single rice crop following a dry fallow period;
3. Flooded pre-season in which the minimum flooding interval is set to 30 days; i.e., shorter flooding periods (usually done to prepare the soil for ploughing) will not be included in this category; and
4. Non-flooded pre-season in which the rice fields were not flooded for > 365 days such as upland crop–paddy rotation.

When activity data for the pre-season water status are not available, aggregated case factors can be used. It is *good practice* to collect more disaggregated activity data and apply disaggregated case of SF_p. Scaling factors for additional water regimes can be applied if country-specific data are available. Note that the scaling factor SF_p indicates the water management condition of a rice field before planting, which consequently affects the seasonal CH_4 emission. SF_p, however, is only used to estimate CH_4 emission during the rice growing period, and cannot be used to quantify CH_4 emissions that occurred before the cultivation period or after harvest (i.e. outside of rice growing season, such as CH_4 emission during winter flooding period).

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

Water regime prior to rice cultivation (schematic presentation showing flooded periods as shaded)		Aggregated case		Disaggregated case	
		Scaling factor (SF_p)	Error range	Scaling factor (SF_p)	Error range
Non flooded pre-season <180 d		1.22	1.08 – 1.37	1.00	0.88 – 1.12
Non flooded pre-season >180 d				0.89	0.80 – 0.99
Flooded pre-season (>30 d)[a,b]				2.41	2.13 – 2.73
Non-flooded pre-season >365 d [c]				0.59	0.41 – 0.84

Source: Scaling factors and error ranges (based on 95% confidential interval) were determined using statistical model and updated database; see Annex 5A.2 for more information.

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

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

[c] Refers to "upland crop - paddy rotation" or fallow without flooding in previous year.

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

EQUATION 5.3
ADJUSTED CH_4 EMISSION SCALING FACTORS FOR ORGANIC AMENDMENTS

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

Where:

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

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

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

TABLE 5.14 (UPDATED)
DEFAULT CONVERSION FACTORS FOR DIFFERENT TYPES OF ORGANIC AMENDMENTS

Organic amendment	Conversion factor (CFOA)	Error range
Straw incorporated shortly (<30 days) before cultivation[a]	1.00	0.85 – 1.17
Straw incorporated long (>30 days) before cultivation[a]	0.19	0.11 – 0.28
Compost	0.17	0.09 – 0.29
Farm yard manure	0.21	0.15 – 0.28
Green manure	0.45	0.36 – 0.57

Source: Conversion factors and error ranges (based on 95% confidential interval) were determined using statistical model and updated database; see Annex 5A.2 for more information.

[a] Straw application means that straws are incorporated into the soil. It does not include cases where straws are just placed on soil surface, and straws that were burnt on the field.

Tier 2

Inventory agencies can use country-specific emission factors from field measurements that cover the conditions of rice cultivation in their respective country. Box 5.2a provides information about measuring methane emissions for developing a baseline emission factor for rice cultivation. It is *good practice* to compile country-specific data bases on available field measurements which supplement the Emission Factor database[13] by other measurement programs (e.g., national) not yet included in this data base. However, certain standard QA/QC requirements apply to these field measurements (see Section 5.5.5).

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

Soil type (SF_s) and rice cultivar (SF_r): In some countries, emission data for different soil types and rice cultivar are available and can be used to derive SFs and SFr, respectively, for Tier 2 method. Both experiments and mechanistic knowledge confirm the importance of these factors, but large variations within the available data do not allow one to define reasonably accurate default values for Tier 1 method.

Tier 3

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

[13] https://www.ipcc-nggip.iges.or.jp/EFDB/main.php

BOX 5.2A (NEW)
***GOOD PRACTICE* GUIDANCE FOR DEVELOPING BASELINE EMISSION FACTORS)EF(FOR CH_4 EMISSIONS FROM RICE CULTIVATION**

The following information provides *good practices* in performing manual measurement of methane emissions using the closed-chamber technique for continuously flooded rice fields with recommended fertilizer application and no organic amendment. The data can be used to develop country- and region-specific EFc.

Chamber Design: It is *good practice* to use lightweight material that is break resistant and inert to reactions with CH_4)e.g., acrylic and PVC(. It may be a rectangular or cylindrical chamber, covering at least two rice hills. The chamber height must be higher than the rice plant. If necessary, use a base with a grove that can be filled with water to ensure a gas-tight closure. The chamber is equipped with a small fan, a thermometer, a vent hole with a stopper, and a gas sampling port)e.g., a flexible tube connected to a valve(.

Field Set up and Experimental Design: Select a field that is homogeneous with respect to soil properties. Use an appropriate experimental design with at least 3 replications.

Sampling Strategies: Sampling can be done 1 or 2 times per day between mid-morning and late morning period, and at least once a week for the whole growing period. More frequent measurements are needed during agricultural management events)e.g., irrigation, drainage, and N fertilization(. All treatments would have to be measured at the same time. At each sampling time, it is *good practice* to obtain 3 to 4 gas samples within 30 minutes after closure of the chamber.

For gas sampling, the use of a syringe or a pump is recommended depending on the required sample volume. Plastic or glass containers can be used for collecting samples and should be transferred to a laboratory and analyzed within the allowable storage period.

Gas Analysis: Use gas chromatograph (GC) equipped with a flame ionization detector (FID) for analysis. Calibrate the GC before every analysis, using certified standard gases.

Data Processing: Use a linear regression of the gas concentration inside the chamber against time to calculate the hourly flux. Identify the reasons of non-linearity)if exists(for the validation and correction of calculated flux. Use trapezoidal integration to calculate cumulative gas emissions from the hourly flux data.

Deriving Emission Factor: Flux data from several sites, regions, or environmental conditions that conform to the requirements for a continuously flooded rice system with no organic amendments, can be used to derive region- or country-specific EFs based on a simple average and standard deviation. The compiler could also derive disaggregated EFs using regression models to predict the values for different regions and/or environmental conditions.

For more details refer to Minamikawa et al.)2015) and Sanders and Wassmann (2014).

5.5.3 Choice of activity data

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

Activity data are primarily based on harvested area statistics, which should be available from a national statistics agency as well as complementary information on cultivation period and agronomic practices. The activity data should be broken down by regional differences in rice cropping practices or water regime (see Box 5.2). Harvested area estimates corresponding to different conditions may be obtained on a countrywide basis through accepted methods of reporting. The use of locally verified areas would be most valuable when they are correlated with available data for emission factors under differing conditions such as climate, agronomic practices, and soil properties. If these data are not available in-country, they can be obtained from international data sources: e.g., the World Rice Statistics on the website of International Rice Research Institute (IRRI[14]), which include harvest area of rice by ecosystem type for major rice producing counties, a rice crop calendar for each country, and other useful information, and the FAOSTAT on the website of FAO[15], where data of rice area harvested can be obtained. The use of locally verified areas would be most valuable when they are correlated with available data for emission

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

[15] www.fao.org/faostat/

factors under differing conditions such as climate, agronomic practices, and soil properties. It may be necessary to consult local experts for a survey of agronomic practices relevant to methane emissions (organic amendments, water management, etc.).

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

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

5.5.4 Example Calculation for Tier 1

An example is provided for estimating methane emission from rice cultivation, with the following background information.

A country in Southeast Asia has rice area of 3 million hectares, with 50percent of the area classified as irrigated, 30percent rainfed, 15percent upland, and 5percent deep water. Irrigated areas are planted for 2 growing seasons annually. Rice growing periods are 102 days, except for deep water rice which has 220 days. For irrigated areas, 50percent is continuously flooded and 50percent is managed with multiple drainage periods. All irrigated areas are not flooded for less than 180 days prior to cultivation, while rainfed and upland areas are not flooded for more than 180 days prior to cultivation. Deepwater rice areas are flooded for 30 days prior to cultivation. For irrigated areas, 2 tonnes/ha of straw residues are incorporated long before cultivation (less than 30 days).

Table 5.14a shows the calculation for total rice harvested area in a given year. Cropping season refers to the number of times rice is harvested per year. The calculation for adjusted daily emission factor is presented in Table 5.14b using Equation 5.2. The scaling factor for organic amendment (SFo), for irrigated rice field, is computed using Equation 5.3 for rice straw application rate of 2 tonnes/ha and conversion factor (CFOA) of 1.0 as provided in Table 5.14. Based on Equation 5.1, the total methane emission is 481.01 Gg CH_4/yr, as shown in Table 5.14c.

TABLE 5.14A (NEW)
CALCULATION FOR TOTAL HARVESTED AREA

Rice Ecosystem	Rice Area (ha)	% of Total Area	Cropping Season (yr^{-1})	Harvested Area ($ha\ yr^{-1}$)
	A	**B**	**C**	**D = (A x C)**
Irrigated				
- Irrigated, continuously flooded	750,000	25	2	1,500,000
- Irrigated, with multiple drainage periods	750,000	25	2	1,500,000
Rainfed	900,000	30	1	900,000
Upland	450,000	15	1	450,000
Deepwater	150,000	5	1	150,000
Total	**3,000,000**	**100**		**4,500,000**

TABLE 5.14B (NEW) CALCULATION FOR ADJUSTED DAILY EMISSION FACTOR					
Rice Ecosystem	**Baseline Emission Factor (EFc) (kg CH_4 ha^{-1} d^{-1}) [from Table 5.13]**	**Scaling Factor for Water Regime during Cultivation (SFw) [from Table 5.14]**	**Scaling Factor for Pre-season Water Regime (SFp) [from Table 5.15]**	**Scaling Factor for Organic Amendment (SFo) [using Equation 5.4 and Table 5.16]**	**Adjusted Daily Emission Factor (EFi) [kg CH_4 ha^{-1} d^{-1}]**
	E	**F**	**G**	**H**	**I= (E x F x G x H)**
Irrigated					
- Irrigated, continuously flooded	1.22	1.00	1.00	1.21	1.48
- Irrigated, with multiple drainage periods	1.22	0.55	1.00	1.21	0.81
Rainfed	1.22	0.54	0.89	1.00	0.59
Upland	1.22	0	0.89	1.00	0.00
Deepwater	1.22	0.06	2.41	1.00	0.18

TABLE 5.14C (NEW) CALCULATION FOR TOTAL METHANE EMISSIONS FROM RICE CULTIVATION				
Rice Ecosystem	**Harvested Area (ha yr^{-1}) [from Table 5.17]**	**Adjusted Daily Emission Factor (EFi) [kg CH_4 ha^{-1} d^{-1}] [from Table 5.18]**	**Cultivation Period (days)**	**Methane Emissions (Gg CH_4 y^{-1})**
	D	**I**	**J**	**K= [(D x I x J)/10^6]**
Irrigated				
- Irrigated, continuously flooded	1,500,000	1.48	102	226.44
- Irrigated, with multiple drainage periods	1,500,000	0.81	102	123.93
Rainfed	900,000	0.59	102	54.16
Upland	450,000	0.00	102	-
Deepwater	150,000	0.18	220	5.94
Total	**4,500,000**			**410.47**

5.5.5 Uncertainty assessment

The general principles of uncertainty assessment relevant for national emission inventories are elucidated in Volume 1, Chapter 3. The uncertainty of emission and scaling factors may be influenced by climatic, temporal, and spatial heterogeneity. Reducing the uncertainty depends on a better understanding of the spatial heterogeneity and correlation among these variables and the complexity of the mechanisms driving methane emission (Zhang et al., 2017).

For this source category, *good practice* should permit determination of uncertainties using standard statistical methods when enough experimental data are available. Studies to quantify some of this uncertainty are rare but available (e.g., for soil type induced variability). The variability found in such studies is assumed to be generally valid. For more detail, see Sass (2002).

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

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

5.5.6 Completeness, time series, QA/QC, and reporting

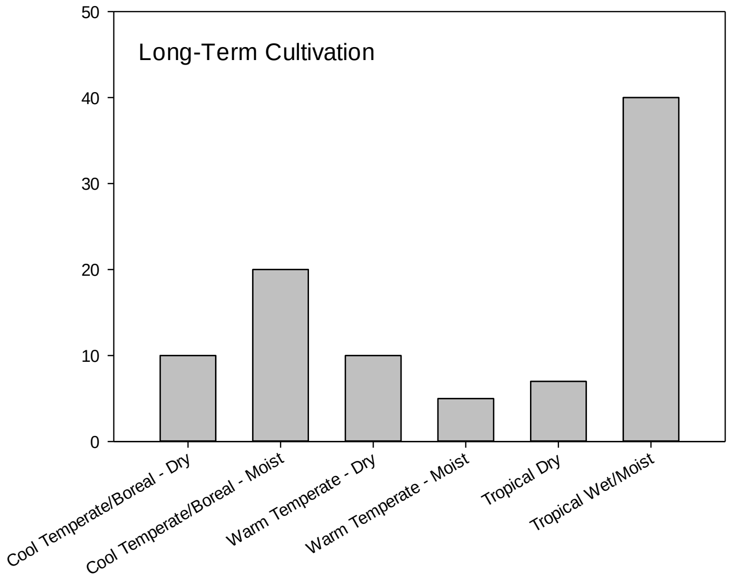
No Refinement.

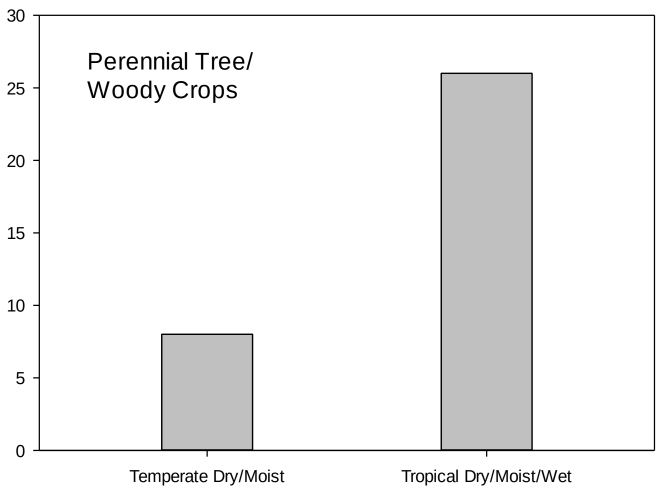
Annex 5A.1 Estimation of default stock change factors for mineral soil C emissions/removals for cropland

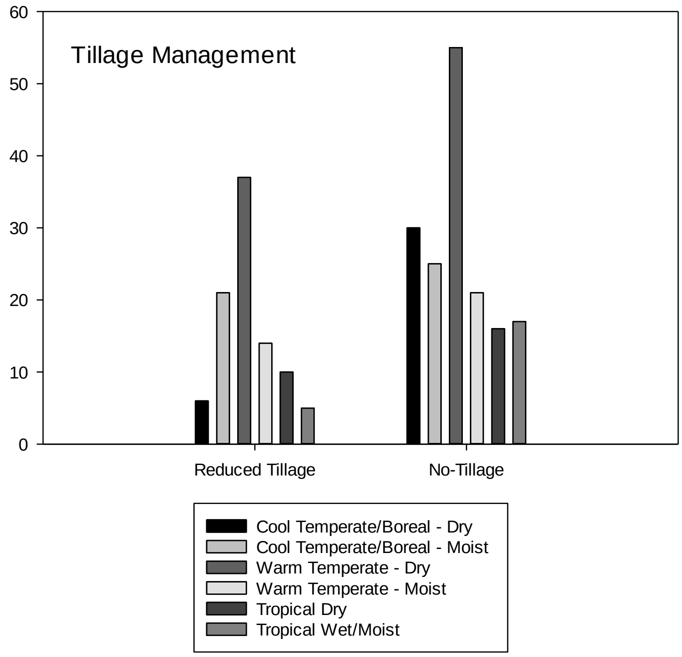
Long-Term Cultivation, Perennial Crops and Tillage Management Factors:

Default stock change factors have been updated in Table 5.5 based on an analysis of a global dataset of experimental results for tillage long-term cultivation, and perennial crops to a 30cm depth. The land-use factor for long-term cultivation and perennial crops represents the change in carbon that occurs after 20 or more years of continuous cultivation or perennial crop production, respectively. Tillage factors represent the effect on C stocks at 20 years following the management change. Data were compiled from published literature based on the following criteria: a) must be an experiment with a control and treatment; b) provide soil organic C stocks or the data needed to compute soil organic C stocks (bulk density, OC content, gravel content); c) provide depth of measurements; d) provide the number of years from the beginning of the experiment to C stock sample collection; and c) provide location information.

There were 303 published studies with 2383 observations for long-term cultivation and perennial tree/woody crops, and 212 published studies with 2046 observations for reduced tillage and no-tillage (References provided at bottom of Table 5.5). The histograms below provide summaries of the distribution of published studies for climate regions.







Semi-parametric mixed effect models were developed to estimate the new factors (Breidt et al., 2007). Several variables were tested including depth, number of years since the management change, climate, the type of management change (e.g., reduced tillage vs. no-till), and the first-order interactions among the variables. Variables and interactions terms were retained in the model if they met an alpha level of 0.05 and decreased the Akiake Information Criterion by two. For depth, data were not aggregated to a standardized set of depths but rather each of the original depth increments were used in the analysis (e.g., 0-5 cm, 5-10 cm, and 10-30 cm) as separate observations of stock changes. Similarly, time series data were not aggregated, even though those measurements are taken from the same plots. Consequently, random effects were included to account for the dependencies in times series data and among data points representing different depths from the same study.

Special consideration was given to representing depth increments in order to avoid aggregating data across increments from the original experiments. Data are collected by researchers at various depths that do not match among studies. We created a custom set of covariates, which are functions of the increment endpoints. These functions come from integrating the underlying quadratic function over the increments. This approach was needed in order to make statistically valid inferences with the semi-parametric mixed effect model techniques, and to avoid errors associated with aggregating data into a uniform set of depth increments.

Using this customized approach, we estimated land use and management factors to a 30 cm depth. Uncertainty was quantified based on the prediction error for the model, and represents a 95percent confidence interval for each of the factor values. The resulting confidence intervals can be used to construct probability distribution functions with a normal density for propagating error through the inventory calculations.

Paddy Rice Land-Use Factors:

Evidence from chronosequences with up to 2000 years of rice cultivation history show rice paddy production accumulates soil organic carbon at a fast rate during the first few decades, and then continues to accumulate carbon at a slower rate until a steady-state is reached at about 300 years (Huang et al., 2015; Kölbl et al., 2014). To update this land use factor for paddy rice, we conducted a literature review and collected the field experiment data of soil carbon stock changes in paddy rice fields that are available in peer-reviewed journals (References provided at bottom of Table 5.5). For each long-term experiment site, data were compiled for conventional management (e.g., normal levels for N, P, K chemical fertilizer applications, rice straw residue management and organic amendments). We calculated the ratio of soil organic carbon (tonne C ha^{-1} for 0-30 cm soil depth) between survey years for the paired comparisons between paddy rice and corresponding native vegetation. The length of time ranged from 15 to 25 years. The resulting estimates capture the large increase in carbon in the first few decades after rice cultivation, and therefore, are considered conservative because carbon can still increase at a slower rate for several more years (Huang et al., 2015; Kölbl et al., 2014). The land use factor for paddy rice is estimated as the average of these ratios, and uncertainty is based on the 2.5 percentile to 97.5 percentile of the distribution of ratios.

Annex 5A.2 Background for developing emission factors and scaling factors for methane emission from paddy field, using scientific literature

1. **Collection of data**

- Since 2004, there exists a large body of field measurements of CH_4 emission from rice fields across the world. The data set of Yan et al., 2005 (which is the data set used in developing the default emission factor and scaling factors in the IPCC *2006 IPCC Guidelines*) was updated with all studies conducted through 30 June 2017, expanding the dataset with observations of CH_4 emission from rice fields around the world.
- A comprehensive search was performed of published literature, which report field measurements of CH_4, as described previously in the paper by Yan et al., 2005. This included a keyword search for topics such as rice or paddy*; methane or CH_4 or greenhouse gas*; and flux* or emission*, in the ISI Web of Science (Thomson Reuters, New York, NY, USA) and Google Scholar (Google, Mountain View, CA, USA).
- From this comprehensive search, the following information was compiled: (i) the average CH_4 flux in the rice-growing season; (ii) integrated seasonal emission; (iii) water regime during and before the rice-growing season; (iv) the timing, type and amount of organic amendment; (v) soil properties (i.e., SOC and soil pH); (vi) location, agroecological zone, and year of experiment or studies; and (viii) duration and season of measurement.
- The following information describes the criteria for selecting data that were included in the data set:

  (i) As suggested previously by Yan et al., 2005, hourly or daily flux is used in the compilation because it has a better index of emission strength than the integrated seasonal emission. When the average daily CH_4 flux was not directly reported, the value is estimated using integrated seasonal emissions divided by the measurement period.

  (ii) Water regimes were categorized into following conditions: (i) continuous flooding; (ii) single drainage; (iii) multiple drainage; (iv) rainfed; and (v) deep water. The pre-season water regime was classified as: (i) non flooded pre-season for less than 180 days; (ii) non flooded pre-season for more than 180 days; (iii) flooded pre-season for more than 30 days; and (iv) non-flooded pre-season for more than 365 days. See Table 5.15 for the illustration of the water regimes before the cultivation period.

  (iii) For organic amendments, the data were classified as (i) straw incorporated shortly (i.e. less than 30 days) before cultivation; (ii) straw incorporated long (i.e. more than 30 days) before cultivation; (iii) compost; (iv) farmyard manure; and (v) green manure. Data for rice straw are expressed in dry weight, while for other organic materials data are expressed in fresh weight.

  (iv) To account for the spatial variability of CH_4 emissions at the global scale, experimental sites were classified into different zones based on their climatic conditions. Using IRRI′s climatic classification (IRRI, 2002), Asian rice fields were categorized into six agro-ecological zone: (i) warm arid and semi-arid tropics; (ii) warm sub-humid tropics; (iii) warm humid tropics; (iv) warm arid and semi-arid sub-tropics with summer rainfall; (v) warm sub-humid sub-tropics with summer rainfall; and (vi) warm/cool humid sub-tropics with summer rainfall. Rice fields in the other region of the world were grouped into three regions, i.e., Latin America, Europe and United States.

  (v) For soil properties, because of the limited availability of information, only soil organic carbon (SOC) and soil pH (as continuous variables) were included in the data set. If soil organic matter content rather than SOC was reported, it was converted to SOC using a Bemmelen index value of 0.58. To meet the requirement of the statistical model, measurements without information for three continuous variables (i.e. SOC data, soil pH and the amount of organic amendment) were excluded. The final dataset used in the analysis included 1089 measurements, from 122 rice fields across the world. In this data set, measurements from Asian rice fields increased from 554 (Yan et al., 2005) to 942. In addition, 147 measurements from other regions of the world were added to the datasets (dataset provided in Wang et al., 2018).

2. **Processing and compilation of data**

Consistent with previous study by Yan et al., (2005), the following linear mixed model, suitable for analyzing unbalanced data (Speed et al., 2013), was used to determine the effect of controlling variables on CH_4 flux from rice fields:

EQUATION 5A.2.1 (NEW)
EFFECT OF CONTROLLING VARIABLES ON CH_4 FLUX FROM RICE FIELDS

$$\ln(flux) = \text{constant} + \text{a} \bullet \ln(SOC) + pH_h + PW_i + WR_j + CL_k + OM_l \bullet \ln(1 + AOM_l)$$

Where:

$\ln(flux)$ = natural logarithm of average CH_4 flux (mg CH_4 m^{-2} h^{-1}) during the rice-growing season

SOC = soil organic carbon content, %

constant = the intercept of the mixed linear model, dimensionless

"a" = represents the effect on soil organic carbon, dimensionless

pH_h = soil pH, dimensionless

PW_i = pre-season water regime (e.g. continuous flooding; single drainage; multiple drainage; rainfed; and deep water), dimensionless

WR_j = water regime in the rice-growing season (e.g. non flooded pre-season for less than 180 days; non flooded pre-season for more than 180 days; flooded pre-season for more than 30 days; and non-flooded pre-season for more than 365 days), dimensionless

CL_k = climate type expressed using IRRI's agro-ecological zone for Asia; other regions were categorized into Europe, Latin America and United States, dimensionless

OM_l = organic amendment (straw incorporated shortly (<30 days) before cultivation, straw incorporated long (>30 days) before cultivation, compost, farmyard manure, and green manure), dimensionless

AOM_l = amount of organic amendment, tonne ha^{-1}

In this model soil pH was treated as a categorical variable and grouped into the following ″h″ classes: <4.5, 4.5-5.0, 5.0-5.5, 5.5-6.0, 6.0-6.5, 6.5-7.0, 7.0-7.5, 7.5- 8.0 and >8.0. For other categorical variables, their corresponding sublevels (i, j, k, l) and descriptions are shown in Tables 5A.2-1.

The last part of Equation 5A.2-1 reflects the effect of the application of organic amendment on CH_4 flux. This effect is an interaction of the type and amount of organic material. In cases where the amount of organic amendment is zero, it is assumed that there is zero application rate for each type of organic material. Obviously, this assumption will result in more data points in the analysis than there are in real observations of organic amendments. To ameliorate this problem, the residuals of observations are weighted with organic amendment as 1 and those without as 0.2 (as the observational result was repeated five times for the five types of organic materials. All the variables were treated as fixed effect, and experimental site was treated as a random effect to address dependencies in data collected from the same experiment.

The effects of the controlling variables on CH_4 flux were computed by fitting Equation 5A.2.1 to field observations using the SPSS Mixed Model procedure (V24.0, SPSS Inc., Chicago, IL, USA).

3. **Developing of global and regional emission factors and scaling factors**

- The estimated effects of various variables were used to derive a default EF. In the model, the CH_4 emissions from rice fields are a combination of the effects of SOC and pH values, pre-season water status, water regime in the rice-growing season, organic amendment and climate. An assumption was made to provide a default EF, that is, all observations in the data set to have a water regime of continuous flooding, a preseason water status of non flooded pre-season <180 d and no organic amendments, while keeping other conditions constant, as stated in the original papers (Yan et al., 2005). Using Equation 5A.2.2, the default EF is derived for continuously flooded rice fields, with a pre-season water status of non flooded pre-season <180 days, and without organic amendment:

EQUATION 5A.2.2 (NEW)
DEFAULT EMISSION FACTOR FOR CONTINUOUSLY FLOODED RICE FIELDS

$$EF = e^{\text{constant}} \bullet \left(\frac{1}{n} \sum_{i=1}^{n} SOC_i^a \bullet e^{pH_i} \bullet e^{CL_i} \right) \bullet e^{PW_{short\_drainage}} \bullet e^{WR_{continuous\_flooding}}$$

Where:

EF = default emission factor derived for continuously flooded rice fields, with a pre-season water status of non-flooded pre-season <180 days, and without organic amendment, mg CH_4 m^{-2} h^{-1} (Note: EF was converted to "kg CH_4 ha^{-1} day^{-1}" in Table 5.11)

constant"a" 'constant' and 'a' = values estimated in Equation 5A.2.1

n = total number of observations in the data set

SOC_i = soil organic carbon content for the i[th] observation, %

pH_i = soil pH for the i[th] observation, dimensionless

CL_i = climate type for the i[th] observation, (expressed using IRRI's agro-ecological zone for Asia, other regions were categorized into Europe, Latin America and United States), dimensionless

$PW_{short\_drainage}$ = pre-season water regime (i.e. as 'non flooded pre-season <180 days), dimensionless

$WR_{continuous\_flooding}$ = water regime in the rice-growing season (i.e. as continuous flooding), dimensionless

The values of scaling factors from the aggregated and disaggregated cases are assumed to be referenced as global and regional scaling factors, respectively. The scaling factors of the disaggregated case for water regime during the rice season and preseason are estimated using the modelling results in Equation 5A.2.1. Firstly, the fluxes of CH_4 for ʹcontinuously floodingʹ during the rice season and ʹnon flooded pre-season <180 dʹ in preseason were assumed to be 1. Then, the corresponding relative fluxes for different water regimes were calculated by the ratios of back-transformed estimates (i.e., exponential function) of different water regimes to back-transformed estimates (i.e., exponential function) of ʹcontinuously floodingʹ during the rice season and ʹnon flooded pre-season <180 dʹ in pre-season. Given the different sizes of observations for various water regimes in the data set, the calculations of the scaling factors for the aggregated case were weighted accordingly. For organic amendment, the fluxes of CH_4 from various form of organic materials were calculated, first with an application amount of 6 t/ha. The CH_4 flux from straw applied shortly (<30 days) before cultivation (6 t/ha) is assumed to be 1, the relative fluxes for other organic materials are then calculated.

See Wang et al. (2018) for more information and datasets used for the analysis.

TABLE 5A.2.1 (NEW) DESCRIPTION OF THE SELECTED VARIABLES THAT CONTROL CH_4 EMISSIONS FROM RICE FIELDS	
Variables	**Description**
Preseason water status	
Flooded pre-season	Permanently flooded rice fields are assumed to have a preseason water regime of ′flooded pre-season′. Late rice (e.g., in China) is usually planted immediately after early rice on the same field and is therefore regarded as having a preseason water regime of ′flooded pre-season′.
Non flooded pre-season >180 d	If rice is planted once a year and the field is not flooded in the non-rice growing season, the preseason water regime is classified as ′non flooded pre-season >180 d′.
Non flooded pre-season <180 d	Rice is planted more than once a year, but there is more than one month of fallow time between the two seasons, ′non-flooded pre-season <180 d′ usually implies preseason drainage.
Non-flooded pre-season >365 d	For measurements conducted on rice fields that are preceded by two upland crops or an upland crop and a drained fallow season, the preseason water regime of such experiments is classified as ′non-flooded pre-season >365 d′.
Water regime in the rice-growing season	
Continuous flooding	Rice is cultivated under continuously flooded condintion but sometimes an end-season drainage before rice harvest included.
Single drainage	One mid-season drainage and an end-season drainage are adopted over the entire rice-growing season.
Multiple drainage	Multiple drainge refers to the management water regime, also called 'intermittent irrigation', in which the number of drainage events was not clear, but there are more than one events during the growing season.
Rainfed, wet season (regular rainfed)	Rice cultivation that relies on rainfall for water, in this case the field is flood prone during the rice-growing season.
Rainfed, dry season (drought prone)	Rice cultivation that relies on rainfall for water, in this case the field is drought prone during the rice-growing season.
Deep water	Rice grown in flooded conditions with water depth more than 50 cm deep.
Organic amendment	
Straw incorporated shortly (<30 days) before cultivation	Straw applied just before rice transplanting as on-season; straw that is left on the soil surface in the fallow season and incorporated into the soil before the next rice transplanting is also categorized as ′straw incorporated shortly (<30 days) before cultivation′. The amount of straw return is expressed in dry weight (t ha^{-1}).
Straw incorporated long (>30 days) before cultivation	Straw incorporated into soils in the previous season (upland crop or fallow) is categorized as ′straw incorporated long (>30 days) before cultivation′. The amount of straw return is expressed in dry weight (t ha^{-1}).
Compost, farmyard manure, green manure	The amount of organic materials is expressed in fresh weight (t ha^{-1}).

Annex 5A.3 Parameterisation of the Tier 2 – Steady State Method for Mineral Soils

The Tier 2 steady state method was parameterised using Bayesian methods after evaluating the sensitivity of the model parameters. The studies that were used to evaluate model sensitivities and parameterise the model are given in Table 5A.3.1.

TABLE 5A.3.1 (NEW)
STUDIES THAT WERE USED TO EVALUATE THE MODEL SENSITIVITIES AND PARAMETERISE THE TIER 2 STEADY-STATE METHOD FOR MINERAL SOILS

References	Site Location	Length of Study (years)	Treatments
Halvorson et al. 1997	Akron, CO, USA	25	Till
Vanotti et al. 1997	Arlington, WI, USA	34	MN
Dimassi et al. 2013	Boigneville, France	41	Till
Juma et al. 1997	Breton, AB, Canada	62	MN, ON
e-RA 2013; Jenkinson 1990	Broadbalk, Rothamsted, UK	153	MN, ON
Pierce and Fortin 1997	East Lansing, MI, USA	12	Till, CC
e-RA 2013; Jenkinson and Johnston 1977	Hoosefield, Rothamsted, UK	146	MN, ON
Dick et al. 1997	Hoytville, OH, USA	42	CR, Till
Campbell et al. 1997	Indianhead, SK, Canada	35	MN, CR
KBS LTER 2017; Collins et al. 2000	Hickory Corners, MI, USA	7	Till
Díaz-Zorita et al. 2004	General Villegas, Argentina	25	Till
Huggins and Fuchs 1997	Lamberton, MN, USA	32	MN
Janzen et al. 1997	Lethbridge, AB, Canada	41	MN, CR
Janzen et al. 1997	Lethbridge, AB, Canada	80	CR
Machado et al. 2008; Marchado 2011; Rasmussen and Smiley 1997	Pendleton, OR, USA	64	MN, ON
Machado et al. 2008; Marchado 2011; Rasmussen and Smiley 1997	Pendleton, OR, USA	55	MN, Till
Dick et al. 1997	South Charleston, OH, USA	29	Till
Küstermann et al. 2013	Scheyern, Germany	12	Till
Maillard et al. 2018	Swift Current, SK, Canada	30	Till, CR
Skjemstad et al. 2004; Schultz 1995	Tarlee, Australia	20	CR
Gregorich et al. 1996	Woodslee, ON, Canada	36	MN
Dick et al. 1997	Wooster, OH, USA	31	CR, Till

MN = Mineral nitrogen additions; ON = organic nitrogen additions; Till = Tillage change; CR = Crop Rotations; CC = Cover Crops

The sensitivity analysis was based on a method developed by Sobol (2001). We evaluated all parameters except for the temperate effect on decomposition (Equation 5.0e) and moisture effects on decomposition (Equation 5.0F). The parameters in these functions were highly correlated so we only evaluated one parameter from each function (t_{opt} for Equation 5.0e and w_1 for Equation 5.0f). A bootstrap sampling method was used to evaluate the total global sensitivity index of the parameters given the log-likelihood value of the mismatch between the model output and the observed data. This information was used to determine if the sample size was sufficient for ranking the sensitivity of the parameters (i.e., minimising the variance enough on the index values to avoid Type 1 error). The sensitivity analysis was conducted in R using the Sensitivity Package (Pujol, Iooss, & Janon, 2017). The results are given in the Table 5A.3.2.

TABLE 5A.3.2 (NEW)
SENSITIVITY OF MODEL PARAMETERS, PARAMETER VALUES AND MINIMUM AND MAXIMUM VALUES FOR THE TIER 2 STEADY-STATE METHOD FOR MINERAL SOILS

Parameter	Practice	Sensitivity	Value (min, max)
$till_{fac}$	Full-till	0.001	3.036 (1.4, 4.0)
	Reduced-till	<0.001	2.075 (1.0, 3.0)
	No-till	n/a1	1
w_s	All	0.003	1.331 (0.8, 2.0)
k_{fac_a}	All	<0.001	7.4
k_{fac_s}	All	0.005	0.209 (0.058, 0.3)
k_{fac_p}	All	0.015	0.00689 (0.005, 0.01)
f_1	All	0.032	0.378 (0.01, 0.8)
f_2	All	0.016	0.368 (0.007, 0.5)
f_3	All	0.003	0.455 (0.1, 0.8)
f_5	All	0.020	0.0855 (0.037, 0.1)
f_6	All	0.040	0.0504 (0.02, 0.19)
f_7	All	<0.001	0.42
f_8	All	<0.001	0.45
t_{opt}	All	0.960	33.69 (30.7, 35.34)
$t_{\max}$	All	n/a2	45

[1] No-till cultivation factor is fixed at a value of 1 based on the model formulation.

[2] The maximum temperature for decomposition was not evaluated because it was highly correlated with the temperature optimum for decomposition.

Bayesian parameterisation techniques were used to determine the probability distributions of the most sensitive parameters, which included parameters with a sensitivity greater than 0.001 (Table 5A.3-2). However, the $till_{fac}$ parameter for reduced-till is included because the parameter for full-till was included. Sampling-importance resampling was used to generate a joint posterior distribution (Rubin, 1998). This approach includes two steps, a) drawing independent random samples from a known prior distribution, and b) resampling the initial draws from step (a) based on importance sampling weights for individual parameter sets. Samples are more likely to be maintained in the posterior distribution with higher likelihoods (Smith & Gelfand, 1992). Uniform priors were selected with an initial sample size $n = 1{,}000{,}000$ and a re-sample size $m = \sqrt{n}$, i.e., 1000, which allows for distributional convergence in the posterior distribution (Givens & Hoeting, 2005). The final posterior distribution was estimated as a truncated multivariate distribution under the assumption that parameter values should not exceed the minimum and maximum values in the posterior distribution. The resulting parameters are given in Table 5A.3-2 and the covariance matrix is given Table 5A.3-3.

TABLE 5A.3.3
COVARIANCE MATRIX FOR THE THREE-POOL STEADY-STATE METHOD FOR MINERAL SOILS

	$till_{fac} - CT$	$till_{fac} - RT$	w_{par}	k_{fac_s}	k_{fac_p}	f_1	f_2	f_3	f_5	f_6	t_{opt}
$till_{fac} - CT$	0.3353436	-0.0007128	0.0124072	0.0077939	0.0000277	0.0007889	-0.0010958	-0.0024497	0.0001000	0.0015558	0.0387919
$till_{fac} - RT$	-0.0007128	0.3239992	-0.0167975	0.0008191	-0.0000013	0.0041484	0.0020256	0.0068887	0.0000775	-0.0017836	0.0047429
w_{par}	0.0124072	-0.0167975	0.1486482	-0.0005654	-0.0001156	0.0084023	0.0055629	-0.0033270	0.0004484	0.0011228	-0.0389749
k_{fac_s}	0.0077939	0.0008191	-0.0005654	0.0032024	0.0000244	0.0022843	0.0015645	0.0008130	-0.0001062	-0.0002235	0.0051276
k_{fac_p}	0.0000277	-0.0000013	-0.0001156	0.0000244	0.0000016	0.0000217	0.0000186	0.0000116	0.0000033	0.0000077	0.0002567
f_1	0.0007889	0.0041484	0.0084023	0.0022843	0.0000217	0.0051767	0.0021790	0.0023559	-0.0001210	-0.0004680	-0.0086628
f_2	-0.0010958	0.0020256	0.0055629	0.0015645	0.0000186	0.0021790	0.0099681	-0.0049865	0.0000755	-0.0005823	-0.0139913
f_3	-0.0024497	0.0068887	-0.0033270	0.0008130	0.0000116	0.0023559	-0.0049865	0.0405470	-0.0001415	0.0001638	-0.0274010
f_5	0.0001000	0.0000775	0.0004484	-0.0001062	0.0000033	-0.0001210	0.0000755	-0.0001415	0.0001479	-0.0000365	-0.0009000
f_6	0.0015558	-0.0017836	0.0011228	-0.0002235	0.0000077	-0.0004680	-0.0005823	0.0001638	-0.0000365	0.0007861	-0.0057748
t_{opt}	0.0387919	0.0047429	-0.0389749	0.0051276	0.0002567	-0.0086628	-0.0139913	-0.0274010	-0.0009000	-0.0057748	0.4347643

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