CHAPTER 6

GRASSLAND

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Contents

Figure

Tables

6 GRASSLAND

6.1 INTRODUCTION

Grasslands cover about one-quarter of the earth's land surface (Ojima *et al.*, 1993) and span a range of climate conditions from arid to humid. Grasslands vary greatly in their degree and intensity of management, from extensively managed rangelands and savannahs – where animal stocking rates and fire regimes are the main management variables – to intensively managed (e.g., with fertilization, irrigation, species changes) continuous pasture and hay land. Grasslands generally have vegetation dominated by perennial grasses, and grazing is the predominant land use.

Grasslands are generally distinguished from "forest" as ecosystems having a tree canopy cover of less than a certain threshold, which varies from region to region. Below-ground carbon dominates in grassland, and is mainly contained in roots and soil organic matter. The transition along rainfall or soil gradients from grassland to forest is often gradual. Many shrublands with high proportions of perennial woody biomass may be considered to be a type of grassland and countries may elect to account for some or all of these shrublands in the Grassland category.

Many grassland species have developed adaptations to cope with grazing and the common perturbation of fire and consequently both the vegetation and soil carbon are relatively resistant to moderate disturbances from grazing and fire regimes (Milchunas and Lauenroth, 1993). In many types of grassland, the presence of fire is a key factor in preventing the invasion of woody species which can significantly affect ecosystem carbon stores (Jackson *et al.*, 2002).

The *1996 IPCC Guidelines* dealt only with emissions from tropical savannah burning and changes in biomass associated with conversion of Grassland to other land use. Three sets of calculations were used to produce estimates of CO_2 emissions due to Grassland conversion: (i) carbon dioxide emitted by burning above-ground biomass, (ii) carbon dioxide released by decay of above-ground biomass, and (iii) carbon dioxide released from soil. No explicit provisions were made for reporting changes in the carbon stocks of grasslands associated with changes in woody perennial biomass cover or from changes in management of these systems.

These *Guidelines* update the *1996 IPCC Guidelines*, and allow for the estimation of carbon emissions and removals in grasslands due to changes in stocks in above-ground and below-ground biomass, emissions of non-CO_2 greenhouse gases due to biomass burning, and carbon emissions and removals in grasslands due to changes in soil C stocks. They incorporate several new methodologies that were developed in the *GPG-LULUCF* (IPCC, 2003). New elements relative to the *1996 IPCC Guidelines* include:

- Methodologies to address C stock changes in the two main pools in grassland: biomass and soils;
- Explicit inclusion of impacts of natural disturbances and fires on managed grassland;
- Estimation of emissions and removals on *Land Converted to Grassland*;
- Extension of methods for estimation of non-CO_2 greenhouse gas emissions due to biomass burning from savannas to all grasslands;
- Estimation of non-CO_2 greenhouse gas emissions due to biomass burning during conversion to grasslands; and
- New stock change rate factors and reference C stocks for soil organic C.

This chapter provides guidelines for default and advanced approaches to estimating and reporting on emissions and removals from grasslands. Methods and guidance are given for *Grassland Remaining Grassland* (Section 6.2) and *Land Converted to Grassland* (Section 6.3). For *Grassland Remaining Grassland*, carbon emissions and removals are based on estimating the effects of changes in management practices on carbon stocks. For lands converted to Grassland, carbon emissions and removals are based on estimating the effects of replacement of one vegetation type by grassland vegetation. If data are not available to segregate grassland area into *Grassland Remaining Grassland* and *Land Converted to Grassland*, the default approach is to consider all grasslands under the category *Grassland Remaining Grassland*.

Inter-annual climatic variability is an important factor for consideration when compiling a carbon inventory for grasslands. Large changes in standing biomass can occur from year to year that is associated with differences in annual rainfall. Inter-annual rainfall variability may also affect management decisions such as irrigation or fertilizer application. The inventory compiler needs to be aware of this and factor these effects into the inventory as appropriate.

6.2 GRASSLAND REMAINING GRASSLAND

Grassland Remaining Grassland includes managed pastures which have always been under grassland vegetation and pasture use or other land categories converted to grassland more than 20 years ago. Constructing a greenhouse gas inventory for the land-use category *Grassland Remaining Grassland* (GG) involves estimation of changes in carbon stock from five carbon pools (i.e., above-ground biomass, below-ground biomass, dead wood, litter, and soil organic matter), as well as emissions of non-CO_2 gases. The principal sources of emissions and removals of greenhouse gases in this category are associated with grassland management and changes in management. The change in C stocks in *Grassland Remaining Grassland* is estimated using Equation 2.3 in Chapter 2. The decision tree in, Figure 1.2 (Chapter 1) provides guidance for selecting the appropriate tier (level of methodological complexity) for the implementation of estimation procedures for GG.

6.2.1 Biomass

Carbon stocks in permanent grassland are influenced by human activities and natural disturbances, including: harvesting of woody biomass, rangeland degradation, grazing, fires, pasture rehabilitation, pasture management, etc. Annual production of biomass in grassland can be large, but due to rapid turnover and losses through grazing and fire, and annual senescence of herbaceous vegetation, standing stock of above-ground biomass in many grasslands rarely exceeds a few tonnes per hectare. Larger amounts can accumulate in the woody component of vegetation, in root biomass and in soils. The extent to which carbon stocks increase or decrease in each of these pools is affected by management practices such as those described above.

This section provides guidance for estimating carbon stock changes in biomass for *Grassland Remaining Grassland*, including increased cover of woody vegetation, effects of organic matter additions and effects of management and liming. The concepts underlying carbon stock changes in biomass of *Grassland Remaining Grassland* are tied to management practices. The decision tree in Figure 2.2 (Chapter 2) provides guidance on the choice of tiers for reporting changes in biomass C stocks.

Because data on below-ground biomass are often lacking for specific ecosystems, a simplified approach based upon below-ground to above-ground biomass ratios is used. With this approach, estimates of below-ground biomass are closely tied to estimates of above-ground biomass. Hence, for simplicity, above-ground and below-ground biomasses are combined for estimation and reporting.

Although the methods for estimating biomass changes are conceptually similar among Grassland, Cropland, and Forest Land, grasslands are unique in a number of ways. Large areas of grasslands are subject to frequent fires that can influence the abundance of woody vegetation, mortality and regrowth of woody and herbaceous vegetation, and the partitioning of carbon above and below ground. Climate variability and other management activities, such as tree and brush removal, pasture improvement, tree planting, as well as overgrazing and degradation can influence biomass stocks. For woody species in savannahs (grassland with trees), the allometric relationships differ from those used in Forest Land because of large numbers of multi-stem trees, large number of shrubs, hollow trees, high proportion of standing dead trees, high root-to-shoot ratios and coppicing regeneration.

6.2.1.1 CHOICE OF METHOD

The decision tree in Chapter 1, Figure 1.2 provides guidance in the selection of the appropriate tier for the implementation of estimation procedures. Estimation of changes in carbon stocks in biomass requires an estimate of changes in stocks of above-ground biomass and changes in carbon stocks in below-ground biomass.

Depending on the tier used and data availability, grassland can be disaggregated by type, region or climatic zone, and management system. It is *good practice* for countries to strive to improve inventory and reporting approaches by advancing to the highest tier possible given national circumstances. It is *good practice* to use a Tier 2 or Tier 3 approach if carbon emissions and removals in *Grassland Remaining Grassland* is a key category and if the sub-category of biomass is considered significant based on principles outlined in Volume 1, Chapter 4.

Tier 1

A Tier 1 approach assumes no change in biomass in *Grassland Remaining Grassland*. In grassland where there is no change in either type or intensity of management, biomass will be in an approximate steady-state (i.e., carbon accumulation through plant growth is roughly balanced by losses through grazing, decomposition and fire). In grassland where management changes are occurring over time (e.g., through introduction of silvopastoral systems, tree/brush removal for grazing management, improved pasture management or other practices), the carbon stock changes can be significant. If it is reasonable to assume that grassland is not a key source, a country may apply the Tier 1 assumption of no change in biomass. However, if information is available to develop reliable estimates of rates of change in biomass in *Grassland Remaining Grassland*, a country may use a higher Tier, even if *Grassland Remaining Grassland* is not a key source, particularly if management changes are likely.

Tier 2

Tier 2 allows for estimation of changes in biomass due to management practices. Two methods are suggested for estimating the carbon stock change in biomass.

Gain-Loss Method *(see Equation 2.7 in Chapter 2):* This method involves estimating the area of grassland according to management categories and the average annual growth and loss of biomass stocks. This requires an estimate of area under *Grassland Remaining Grassland* according to different climate or ecological zones or grassland types, disturbance regime, management regime, or other factors that significantly affect biomass carbon pools and the growth and loss of biomass according to different grassland types.

Stock-Difference Method *(see Equation 2.8 in Chapter 2):* The Stock-Difference Method involves estimating the area of grassland and the biomass stocks at two periods of time, t_1 and t_2. The average annual biomass stock differences for the inventory year are obtained by dividing the stock difference by the period (years) between inventories. This method is feasible for countries which have periodic inventories, and may be more suitable for countries adopting Tier 3 methods. This method may not be well suited to regions with very variable climates and may produce spurious results unless annual inventories can be made.

Tier 3

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

For Tier 3, countries should develop their own methodologies and parameters for estimating changes in biomass. These methodologies may be derived from Equation 2.7 or Equation 2.8 specified above, or may be based on other approaches. The method used needs to be clearly documented.

Estimates of carbon stocks in biomass at the national level should be determined as part of a national grasslands inventory, national level models, or from a dedicated greenhouse gas (GHG) inventory programme, with periodic sampling according to the principles set out in Volume 1. Inventory data can be coupled with modelling studies to capture the dynamics of all grassland carbon pools.

Tier 3 methods provide estimates of greater certainty than lower tiers and feature a greater link between individual carbon pools. Some countries have developed disturbance matrices that provide a carbon reallocation pattern among different pools for each type of disturbance.

6.2.1.2 CHOICE OF EMISSION/REMOVAL FACTORS

Emission and removal factors that are required to estimate the changes in biomass resulting from management include biomass growth rate, loss of biomass, and expansion factor for below-ground biomass. Emission and removal factors are used to estimate biomass growth and loss resulting from encroachment of woody perennial vegetation into grassland, degradation due to overgrazing, and other management effects.

Tier 1

Tier 1 is to be chosen when there are no significant emissions or removals in *Grassland Remaining Grassland*. The assumption in Tier 1 is that the biomass in all *Grassland Remaining Grassland* is stable. Countries experiencing significant changes in grassland management or disturbance are encouraged to develop domestic data to estimate this impact, and report it under a Tier 2 or 3 methodology.

Tier 2

It is *good practice* to use country level data on biomass C stocks for different grassland categories, in combination with default values, if country or regional values are not available for some grassland categories. Country-specific values for net biomass increment as well as losses from harvested live trees and grasses to harvest residues and decomposition rates, in the case of the Gain-Loss Method, or the net change in biomass stocks, in the case of the Stock-Difference Method can be derived from country-specific data, taking into account the grassland type, the rate of biomass utilization, harvesting practices and the amount of damaged vegetation during harvesting operations. Country-specific values for disturbance regimes should be derived from scientific studies.

Estimating below-ground biomass can be an important component of biomass surveys of grassland but field measurements are laborious and difficult. Hence, expansion factors to estimate below-ground biomass from above-ground biomass are often used. Adaptations to fire and grazing have led to higher root-to-shoot ratios compared to many other ecosystems; thus biomass expansion factors from undisturbed ecosystems cannot be applied without modification. Root-to-shoot ratios vary significantly at both individual species (e.g., Anderson *et al.*, 1972*)* and community scales (e.g., Jackson *et al.*, 1996; Cairns *et al.*, 1997*).* Thus it is recommended to use, as far as possible, empirically-derived root-to-shoot ratios specific to a region or vegetation type. Table 6.1 provides default root-to-shoot ratios (all vegetation) for grassland ecosystems in the major climate zones of the world (IPCC climate zones taken from Annex 3A.5). These values can be used as defaults when countries do not have more specific information to develop country-specific ratios. Ratios for woodland/savannah and shrublands are also included for use by countries that include these lands in the grassland section of their inventory.

TABLE 6.1
DEFAULT EXPANSION FACTORS OF THE RATIO OF BELOW-GROUND BIOMASS TO ABOVE-GROUND BIOMASS (R) FOR THE MAJOR GRASSLAND ECOSYSTEMS OF THE WORLD

Land-use category	Vegetation type	Approximate IPCC climate zone[1]	R [tonne d.m. below-ground biomass (tonne d.m. above-ground biomass) $^{-1}$]	n	Error[2]
Grassland	Steppe/tundra/prairie grassland	Boreal – Dry & Wet Cold Temperate – Wet Warm Temperate – Wet	4.0	7	± 150%
	Semi-arid grassland	Cold Temperate – Dry Warm Temperate – Dry Tropical – Dry	2.8	9	± 95%
	Sub-tropical/ tropical grassland	Tropical – Moist & Wet	1.6	7	± 130%
Other	Woodland/savannah		0.5	19	± 80%
	Shrubland		2.8	9	± 144%

[1] Classification of the source data was by grassland biome types and thus correspondence to the IPCC climate zones are approximations.
[2] Error estimates are given as two times standard deviation, as a percentage of the mean.

Tier 3
Tier 3 approaches consist of using a combination of dynamic models and inventory measurements of biomass stock changes. This approach does not employ simple stock changes or emission factors *per se*. Estimates of emissions/removals using model-based approaches are derived from the interaction of multiple equations that estimate the net change of biomass stocks within the models. Models, jointly with periodic sampling-based stock estimates similar to those used in detailed forest inventories, could be applied to estimate stock changes or inputs and outputs as in Tier 2 to make spatial extrapolations for grassland areas. For example, validated species-specific growth models that incorporate management effects such as grazing intensity, fire, and fertilization, with corresponding data on management activities, can be used to estimate net changes in grassland biomass over time.

6.2.1.3 CHOICE OF ACTIVITY DATA

Activity data consist of areas of *Grassland Remaining Grassland* summarised by major grassland types, management practices, and disturbance regimes. Total grassland areas should be determined according to Approaches laid out in Chapter 3 and should be consistent with those reported under other sections of this chapter, notably under the DOM and soil C sections of *Grassland Remaining Grassland*. The assessment of changes in biomass will be greatly facilitated if this information can be used in conjunction with national soils and climate data, vegetation inventories, and other biophysical data.

6.2.1.4 CALCULATION STEPS FOR TIERS 1 AND 2

The following summarizes steps for estimating change in carbon stocks in biomass (ΔC_B)

Tier 1
Once countries choose to apply a Tier 1 approach, no further work is necessary, as the ecosystem is assumed to be in steady state, where no changes in carbon stocks are expected to occur. Thus, there is no worksheet for biomass.

Tier 2 (Gain-Loss Method – Equation 2.7 in Chapter 2)
Step 1: Determine the grassland categories to be used in this assessment and the representative areas. The categories consist of definitions of the grassland type (e.g., stratified by climate zone and species assemblage) and the state or management of that type [e.g., 'degraded tall grass prairie' (USA, Canada), or 'grazed campo limpo' (Brazil)]. Area data should be obtained using the methods described in Chapter 3.

Step 2: Determine the biomass increment and loss of woody biomass (using Equations 2.9 and 2.11), for each stratum, and use these to estimate the net change in biomass (using Equation 2.7). Where data exist only for above-ground biomass, countries may use expansion factors for below-ground to above-ground biomass ratios to estimate the below-ground portion of the biomass. Multiply the change in biomass by the carbon content of the dry biomass. The default value is 0.50 tonne of C per tonne of biomass (dry weight). A Tier 2 approach may use default expansion factors provided in Table 6.1 to estimate below-ground biomass when country-specific factors are not available.

Step 3: Determine the average biomass increment and loss of herbaceous biomass and use these to estimate the net change in biomass using Equation 2.7. An approach based upon Equations 2.9 and 2.11 may be devised for herbaceous biomass. Where data exist only for above-ground biomass, countries may use expansion factors for below-ground to above-ground biomass ratios to estimate the below-ground portion of the biomass. Multiply the change in biomass by the carbon content of the dry biomass. The default value is 0.47 tonne of C per tonne of biomass (dry weight). This default value differs from the one in the *GPG-LULUCF* (IPCC, 2003), but is more realistic for herbaceous biomass. A Tier 3 approach requires country-specific or ecosystem-specific expansion factors. A Tier 2 approach may use default expansion factors provided in Table 6.1 to estimate below-ground biomass when country specific factors are not available.

Step 4: If increment and loss were calculated on a per area basis, estimate the total change in the biomass carbon stocks for each category by multiplying the representative area of each category by the net change in biomass for that category. Otherwise, proceed to step 5.

Step 5: Estimate the total net change in carbon stocks in biomass by summing up the net changes in herbaceous and woody perennial biomass.

Tier 2 (Stock-Difference Method – Equation 2.8 in Chapter 2)
Step 1: Same as for Gain-Loss Method (see above).

Step 2: Determine the inventory time interval, the average woody biomass at the initial inventory (t_1), and the average woody biomass at the final inventory (t_2). Use these figures to estimate the net annual change in woody biomass (Equation 2.8). Where data exist only for above-ground biomass, countries may use expansion factors for below-ground to above-ground biomass ratios (R) to estimate the below-ground portion of the biomass. Multiply the change in biomass by the carbon content of the dry biomass. The default value is 0.50 tonne of C per tonne of biomass (dry weight). A Tier 3 approach requires country-specific or ecosystem-specific expansion factors. A Tier 2 approach may use default expansion factors provided in Table 6.1 to estimate below-ground biomass or country-specific or ecosystem-specific expansion factors, if available. Note the R values in Table 6.1 are whole ecosystem R values. Thus, to use these values, one must first sum the above-ground herbaceous and woody biomass and then multiply by R to obtain the value for below-ground biomass.

Step 3: Determine the inventory time interval, the average herbaceous biomass at the initial inventory (Ct1), and the herbaceous biomass at the final inventory (Ct_2). Use these figures, and the inventory time interval, to estimate the net annual change in herbaceous biomass (Equation 2.8). Where data exist only for above-ground biomass, countries may use expansion factors for below-ground to above-ground biomass ratios to estimate the below-ground portion of the biomass. Multiply the change in biomass by the carbon content of the dry biomass. The default value is 0.47 tonne of C per tonne of biomass (dry weight). This default value differs from the one in the *GPG-LULUCF* (IPCC, 2003), but is more realistic for herbaceous biomass. A Tier 3 approach requires country-specific or ecosystem-specific expansion factors. A Tier 2 approach may use default expansion factors provided in Table 6.1 to estimate below-ground biomass when country specific factors are not available.

Step 4: Estimate the total change in the biomass carbon stocks for each category using Equation 2.8.

Step 5: Estimate the total net change in carbon stocks in biomass by summing up the net changes in herbaceous and woody perennial biomass.

6.2.1.5 UNCERTAINTY ASSESSMENT

This section considers source-specific uncertainties relevant to estimates made for biomass C in *Grassland Remaining Grassland*. Two sources of uncertainty exist in C inventories: 1) uncertainties in land-use and management activity and environmental data; 2) uncertainties in carbon increase and loss, carbon stocks and expansion factor terms in the stock change/emission factors for Tier 2 approaches, model structure/parameter error for Tier 3 model-based approaches, or measurement error/sampling variability associated with Tier 3 measurement-based inventories. In general, precision of an inventory is increased and confidence ranges are narrower with greater sampling intensity to estimate values for each category, while reducing bias (i.e., improve accuracy) is more likely to occur through the development of a higher Tier inventory that incorporates country-specific information. Error estimates (i.e., standard deviations, standard error, or ranges) must be calculated for each of the country-defined terms used in a basic uncertainty assessment.

Uncertainties in land-use and management data will need to be addressed by the inventory compiler, and then combined with uncertainties for default factors and reference C stocks using an appropriate method, such as simple error propagation equations. For Tier 2 methods, country-specific information is incorporated into the inventory analysis for purposes of reducing bias. It is *good practice* to evaluate dependencies among the factors, reference C stocks or land-use and management activity data. In particular, strong dependencies are common in land-use and management activity data because management practices tend to be correlated in time and space. Combining uncertainties in stock change/emission factors, reference C stocks and activity data can be done using methods such as simple error propagation equations or Monte-Carlo procedures to estimate means and standard deviations for the change in biomass C stocks (Ogle *et al*., 2003, Vanden Bygaart *et al*., 2004).

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

Expansion factor uncertainties

Default uncertainty estimates provided in Table 6.1 can be used for the uncertainty expressed for below-ground biomass expansion factors. Uncertainties associated with expansion factors for carbon content of woody and herbaceous biomass, are relatively small, and are on the order of 2 to 6 percent. For Tiers 2 and 3 estimates, country-specific or regionally derived values will be used. These reference C stocks and stock change factors can have inherently high uncertainties, particularly bias, when applied to specific countries. Defaults represent averaged values of land-use and management impacts or reference C stocks that may vary from site-specific values. It is *good practice* for countries to determine the uncertainties of their default factors for above-ground and below-ground biomass.

Activity data uncertainties

Area data and estimates of uncertainty should be obtained using the methods in Chapter 3. Tiers 2 and 3 approaches may also use finer resolution activity data, such as area estimates for different climatic regions or for grassland management systems within national boundaries. The finer-resolution data will reduce uncertainty levels when associated with carbon accumulation factors defined for those finer-scale land databases. If using aggregate land-use area statistics for activity data (e.g., FAO data), the inventory agency may have to apply a default level of uncertainty for the land area estimates (±50%). However, it is *good practice* for the inventory compiler to derive uncertainties from country-specific activity data instead of using a default level. For Tiers 2 and 3, use of higher resolution activity data (such as area estimates for different climatic regions or for grassland management systems within national boundaries) will reduce uncertainty levels when all necessary carbon accumulation/loss parameters are suitably stratified. Uncertainties in land-use activity statistics may be reduced through a better national system, such as developing or extending a ground-based survey with additional sample locations and/or incorporating remote sensing to provide additional coverage. It is *good practice* to design a classification system that captures the majority of land-use and management activities with a sufficient sample size to minimize uncertainty at the national scale.

6.2.2 Dead organic matter

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

Dead wood is a diverse pool which is difficult to measure in the field, with associated uncertainties about rates of transfer to litter, soil, or emissions to the atmosphere. Amounts of dead wood depend on the time since last disturbance, the amount of input (mortality) at the time of the disturbance, natural mortality rates, decay rates, and management.

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

6.2.2.1 CHOICE OF METHOD

Estimation of changes in carbon stocks in DOM requires an estimate of changes in stocks of dead wood and changes in litter stocks (refer to Equation 2.17 in Chapter 2). The decision tree in Chapter 1, Figure 1.2 helps in the selection of the appropriate tier level for the implementation of estimation procedures.

The dead wood and litter pools are treated separately, but the method for estimating changes in each pool is the same.

Tier 1
The Tier 1 method assumes that the dead wood and litter stocks are at equilibrium, so there is no need to estimate the carbon stock changes for these pools. Thus, there is no worksheet provided for DOM in *Grassland Remaining Grassland*. Countries experiencing significant changes in grassland types or disturbance or management regimes in their grasslands are encouraged to develop domestic data to quantify this impact and report it under Tier 2 or 3 methodologies.

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

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

Stock-Difference Method (Equation 2.19 in Chapter 2): This method involves estimating the area of grassland and the dead wood and litter stocks at two periods of time, t_1 and t_2. The dead wood and litter stock changes for the inventory year are obtained by dividing the stock changes by the period (years) between two measurements. The Stock-Difference Method is feasible for countries, which have periodic grassland inventories. This method may not be well suited to regions with very variable climates and may produce spurious results unless annual inventories can be made. This method is more suitable for countries adopting Tier 3 methods. Tier 3 methods are used where countries have country-specific emission factors, and substantial national data. Country-defined methodology may be based on detailed inventories of permanent sample plots for their grasslands and/or models.

6.2.2.2 CHOICE OF EMISSION/REMOVAL FACTORS

Carbon fraction: The carbon fraction of dead wood and litter is variable and depends on the stage of decomposition. Wood is much less variable than litter and a value of 0.50 tonne C (tonne d.m.)$^{-1}$ can be used for the carbon fraction. The carbon fraction values for litter in grasslands range from 0.05 to 0.50 (Naeth *et al*., 1991; Kauffman *et al*., 1997). When country-specific or ecosystem-specific data are not available, it is suggested that a carbon fraction value of 0.40 be used.

Tier 1
Estimates of emission/removal factors are not needed, as the assumption in Tier 1 is that the DOM carbon stocks in all *Grassland Remaining Grassland* are stable.

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

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

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

Tier 3 methods provide estimates of greater certainty than lower tiers and feature greater links between individual carbon pools. Some countries have developed disturbance matrices (see Table 2.1 in Chapter 2) that provide a carbon reallocation pattern among different pools for each type of disturbance. Other important parameters in a modelled DOM carbon budget are decay rates, which may vary with the type of wood and microclimatic conditions, and site preparation procedures (e.g., controlled broadcast burning, or burning of piles).

6.2.2.3 CHOICE OF ACTIVITY DATA

Activity data consist of areas of *Grassland Remaining Grassland* summarised by major grassland types, management practices, and disturbance regimes. Total grassland areas should be consistent with those reported under other sections of this chapter, notably under the biomass section of *Grassland Remaining Grassland*. The assessment of changes in dead organic matter will be greatly facilitated if this information can be used in conjunction with national soils and climate data, vegetation inventories, and other geophysical data. Area estimates should be obtained using methods described in Chapter 3.

6.2.2.4 CALCULATION STEPS FOR TIERS 1 AND 2

The following summarizes steps for estimating change in DOM carbon stocks:

Tier 1
Once the decision is made that reporting for this category will be done using a Tier 1 approach, no further work is necessary as the ecosystem is assumed to be in steady-state and there are no expected changes in dead wood or litter carbon stocks.

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

Step 1: Determine the categories of grassland types to be used in this assessment and the representative area.

Step 2: Determine the input and output rates of dead wood and litter to the respective pools. Identify values from inventories or scientific studies for the average inputs and outputs of dead wood or litter for each category. No default factors exist for inputs and outputs from these pools, so countries should use locally available data. Calculate the net change in the DOM pools by subtracting the outputs from the inputs. Negative values indicate a net decrease in the stock.

Step 3: Determine the net change in DOM stocks for each category by subtracting the outputs from the inputs. Convert the net change in DOM biomass stocks to carbon stocks for each category by multiplying the carbon fraction. The default carbon fractions are 0.50 tonne C (tonne d.m.)$^{-1}$ for dead wood and 0.40 tonne C (tonne d.m.)$^{-1}$ for litter. A Tier 2 approach requires country-specific or ecosystem-specific stock change rate factors.

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

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

Tier 2 (Stock-Difference Method) – Equation 2.19 in Chapter 2

Each of the DOM pools is to be treated separately, but the method for each pool is the same.

Step 1: Determine the categories of grassland types to be used in this assessment and the representative area.

Step 2: Determine the net change in DOM stocks for each category. From the inventory data, identify the inventory time interval, the average stock of DOM at the initial inventory (t_1), and the average stock of DOM at the final inventory (t_2). Use these figures to estimate the net annual change in DOM stocks by subtracting the DOM stock at t_1 from the DOM stock at t_2 and dividing this difference by the time interval (Equation 2.19). A negative value indicates a decrease in the DOM stock.

Step 3: Determine the net change in DOM carbon stocks for each category. Determine the net change in DOM carbon stocks by multiplying the net change in DOM stocks for each category by the carbon fraction of the DOM. A Tier 2 approach requires country-specific or ecosystem-specific expansion factors.

Steps 4 and 5: Same as for Gain-Loss Method.

6.2.2.5 UNCERTAINTY ASSESSMENT

This section considers source-specific uncertainties relevant to estimates made for DOM in *Grassland Remaining Grassland*. Two sources of uncertainty exist in C inventories: 1) uncertainties in land-use and management activity and environmental data; 2) uncertainties in carbon increase and loss, carbon stocks and expansion factor terms in the stock change/emission factors for Tier 2 approaches, model structure/parameter error for Tier 3 model-based approaches, or measurement error/sampling variability associated with Tier 3 measurement-based inventories. In general, precision of an inventory is increased and confidence ranges are narrower with greater sampling intensity to estimate values for each category, while reducing bias (i.e., improve accuracy) is more likely to occur through the development of a higher Tier inventory that incorporates country-specific information. Error estimates (i.e., standard deviations, standard error, or ranges) must be calculated for each of the country-defined terms used in a basic uncertainty assessment.

Uncertainties in land-use and management data will need to be addressed by the inventory compiler, and then combined with uncertainties for default factors and reference C stocks using an appropriate method, such as simple error propagation equations. For Tier 2 methods, country-specific information is incorporated into the inventory analysis for purposes of reducing bias. It is *good practice* to evaluate dependencies among the factors, reference C stocks or land-use and management activity data. In particular, strong dependencies are common in land-use and management activity data because management practices tend to be correlated in time and space. Combining uncertainties in stock change/emission factors, reference C stocks and activity data can be done using methods such as simple error propagation equations or Monte-Carlo procedures to estimate means and standard deviations for the change in DOM C stocks (Ogle *et al*., 2003; Vanden Bygaart *et al*., 2004).

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

Emission/removal factor uncertainties

No uncertainty analysis is needed for Tier 1 since the default assumption is unchanging carbon stocks in DOM. For Tiers 2 and 3 estimates, country-specific or regionally derived values will be used. These reference C stocks and stock change factors can have inherently high uncertainties, particularly bias, when applied to specific countries. Defaults represent averaged values of land-use and management impacts or reference C stocks that may vary from site-specific values. It is *good practice* for countries to determine the uncertainties of their default factors for dead wood and litter.

Activity data uncertainties

Area data and estimates of uncertainty should be obtained using the methods in Chapter 3. If using aggregate land-use area statistics for activity data (e.g., FAO data), the inventory agency may have to apply a default level of uncertainty for the land area estimates ($\pm$50%). However, it is *good practice* for the inventory compiler to derive uncertainties from country-specific activity data instead of using a default level. For Tiers 2 and 3, use of higher resolution activity data (such as area estimates for different climatic regions or for grassland management systems within national boundaries) will reduce uncertainty levels when all necessary carbon accumulation/loss parameters are suitably stratified. Uncertainties in land-use activity statistics may be reduced through a better national system, such as developing or extending a ground-based survey with additional sample locations and/or incorporating remote sensing to provide additional coverage. It is *good practice* to design a classification system that captures the majority of land-use and management activities with a sufficient sample size to minimize uncertainty at the national scale.

6.2.3 Soil carbon

This section deals with the impacts of grassland management on soil organic C stocks, primarily by influencing C inputs to the soil, and thus soil C storage, by affecting net primary production, root turnover, and allocation of C between roots and shoots. Soil C stocks in grassland are influenced by fire, grazing intensity, fertilizer management, liming, irrigation, re-seeding with more or less productive grass species and mixed swards with N-fixing legumes (Conant *et al*., 2001; Follett *et al*., 2001; Ogle *et al*., 2004). In addition, drainage of organic soils for grassland management causes losses of soil organic C (Armentano and Menges, 1986).

General information and guidance for estimating changes in soil C stocks are provided in Chapter 2, Section 2.3.3 (including equations), and this section needs to be read before proceeding with a consideration of specific guidelines dealing with grassland soil C stocks. The total change in soil C stocks for grassland 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 (if estimated at Tier 3). This section provides specific guidance for estimating soil organic C stocks. There is a general discussion in Section 2.3.3.1 on soil inorganic C and no additional information on this is provided here.

To account for changes in soil C stocks associated with *Grassland Remaining Grassland*, countries need to have, at a minimum, estimates of grassland areas 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 grassland, can be used as a starting point, along with knowledge of country experts about the approximate distribution of land management systems (e.g., degraded, nominal and improved grassland/grazing systems). Grassland management classes must be 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 land use on suitable climate and soil maps.

6.2.3.1 CHOICE OF METHOD

Inventories can be developed using a Tier 1, 2 or 3 approach, with each successive Tier requiring more details and resources than the previous one. It is also possible that countries will use different tiers to prepare estimates for the separate sub-categories of soil C (i.e., soil organic C stocks changes in mineral and organic soils; and stock changes associated with soil inorganic C pools). Decision trees are provided for mineral (Figure 2.4) and organic soils (Figure 2.5) in Section 2.3.3.1 (Chapter 2) to assist inventory compilers with the 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 storage. After a finite transition period, one can assume a steady state for this stock. 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). Note that area of exposed bedrock in grasslands are not included in the soil C stock calculation (assume a stock of 0). In practice, country-specific data on grassland management activity should be obtained and classified into appropriate land management systems, and then stratified by IPCC climate regions and soil types (see Chapter 3). Soil organic C stocks (SOC) are estimated for each time period in the inventory using default reference carbon stocks (SOC_{ref}) and default stock change factors (F_{LU}, F_{MG}, F_I).

Tier 2

The Tier 2 method for mineral soils also uses Equation 2.25 (Chapter 2), but the inventory approach is further developed with country-specific information to better specify stock change factors, reference C stocks, climate regions, soil types, and/or the land management classification system.

Tier 3

Tier 3 approaches do not employ simple stock change factor *per se*, but rather use dynamic models and/or detailed soil C inventory measurements as the basis for estimating annual stock changes.

Estimates of stock changes using model-based approaches are computed from the coupled equations that estimate the net change of soil carbon. A variety of models designed to simulate soil carbon dynamics exist (for example, see reviews by McGill *et al.*, 1996; Smith *et al.*, 1997). Key criteria in selecting an appropriate model include its capability of representing all of the relevant management practices/systems for grasslands; model inputs (i.e., driving variables) are compatible with the availability of country-wide input data; and the model sufficiently represents stock changes based on comparisons with 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. In contrast to a network associated with model validation, a much higher density of benchmark sites will be needed to adequately represent the combination of land-use and management systems, climate and soil types. Additional guidance is provided in Section 2.3.3.1 (Chapter 2).

Organic soils

Tier 1

Equation 2.26 (Chapter 2) is used to estimate C stock change in managed grassland on organic soils (e.g., peat-derived, Histosols). The methodology is to stratify managed organic soils by climate region and assign a climate-specific annual emission rate. Land areas are multiplied by the emission factor and then summed to derive annual C emissions. Natural grasslands that may be used for seasonal grazing but have not been artificially drained should not be included in this category.

Tier 2

The Tier 2 approach also uses Equation 2.26 (Chapter 2), but country-specific information is incorporated to better specify emission factors, climate regions, and/or the land management classification system.

Tier 3

Tier 3 approaches for organic soils use dynamic models and/or measurement networks (*see Mineral Soils* above for additional discussion).

6.2.3.2 CHOICE OF STOCK CHANGE AND EMISSION FACTOR

Mineral soils

Tier 1

For the Tier 1 approach, default stock change factors are provided in Table 6.2, which includes values for land use factor (F_{LU}), input factor (F_I), and management factor (F_{MG}). The method and studies that were used to derive the default stock change factors are provided in Annex 6A.1. The time dependence (D) is 20 years for default stock change factors in grasslands, and they represent the influence of management to a depth of 30cm. Default reference soil organic C stocks are found in Table 2.3 of Chapter 2. The reference stock estimates are for the top 30cm of the soil profile, to be consistent with the depth increment for default stock change factors.

Tier 2

Estimation of country-specific stock change factors is an important advancement for improving an inventory that can be developed in the Tier 2 approach. Derivations of management factor (F_{MG}) and input factor (F_I) factor are based on experimental comparisons to nominally-managed grasslands with medium input, respectively, because these classes are considered the nominal practices in the IPCC default classification scheme for management systems (see Choice of Activity Data). It is considered *good practice* to derive values for more detailed classification schemes of management, climate and soil types, if there are significant differences in the stock change factors among finer categories based on an empirical analysis. Reference C stocks can also be derived from country-specific data in a Tier 2 approach. Additional guidance is provided in Section 2.3.3.1 (Chapter 2).

Tier 3

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

TABLE 6.2 **RELATIVE STOCK CHANGE FACTORS FOR GRASSLAND MANAGEMENT**					
Factor	**Level**	**Climate regime**	**IPCC default**	**Error** [1,2]	**Definition**
Land use (F_{LU})	All	All	1.0	NA	All permanent grassland is assigned a land-use factor of 1.
Management (F_{MG})	Nominally managed (non –degraded)	All	1.0	NA	Represents non-degraded and sustainably managed grassland, but without significant management improvements.
Management (F_{MG})	Moderately degraded grassland	Temperate /Boreal	0.95	± 13%	Represents overgrazed or moderately degraded grassland, with somewhat reduced productivity (relative to the native or nominally managed grassland) and receiving no management inputs.
		Tropical	0.97	± 11%	
		Tropical Montane[3]	0.96	± 40%	
Management (F_{MG})	Severely degraded	All	0.7	± 40%	Implies major long-term loss of productivity and vegetation cover, due to severe mechanical damage to the vegetation and/or severe soil erosion.
Management (F_{MG})	Improved grassland	Temperate /Boreal	1.14	± 11%	Represents grassland which is sustainably managed with moderate grazing pressure and that receive at least one improvement (e.g., fertilization, species improvement, irrigation).
		Tropical	1.17	± 9%	
		Tropical Montane[3]	1.16	± 40%	
Input (applied only to improved grassland) (F_I)	Medium	All	1.0	NA	Applies to improved grassland where no additional management inputs have been used.
Input (applied only to improved grassland) (F_I)	High	All	1.11	± 7%	Applies to improved grassland where one or more additional management inputs/improvements have been used (beyond that is required to be classified as improved grassland).

[1] ± two standard deviations, expressed as a percent of the mean; where sufficient studies were not available for a statistical analysis a default, based on expert judgement, of ± 40% is used as a measure of the error. NA denotes 'Not Applicable', for factor values that constitute reference values or nominal practices for the input or management classes.

[2] 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.

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

Note: See Annex 6A.1 for estimation of default stock change factors for mineral soil C emissions/removals for Grassland.

Organic soils

Tier 1

For a Tier 1 approach, default emission factors are provided in Table 6.3 to estimate the loss of C associated with drainage of organic soils.

Tier 2

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

Tier 3

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

TABLE 6.3 ANNUAL EMISSION FACTORS (EF) FOR DRAINED GRASSLAND ORGANIC SOILS		
Climatic temperature regime	**IPCC default (tonne C ha^{-1} yr^{-1})**	**Error [1]**
Boreal/Cold Temperate	0.25	± 90%
Warm Temperate	2.5	± 90%
Tropical/Sub-Tropical	5.0	± 90%

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

These values represent one quarter of the loss on drained croplands (see Table 5.6 in Chapter 5), which is approximately the proportional loss of C on drained grassland relative to croplands according to data presented in Armentano and Menges (1986). These values have a degree of uncertainty as reflected in the error column.

6.2.3.3 CHOICE OF ACTIVITY DATA

Mineral soils

Tier 1

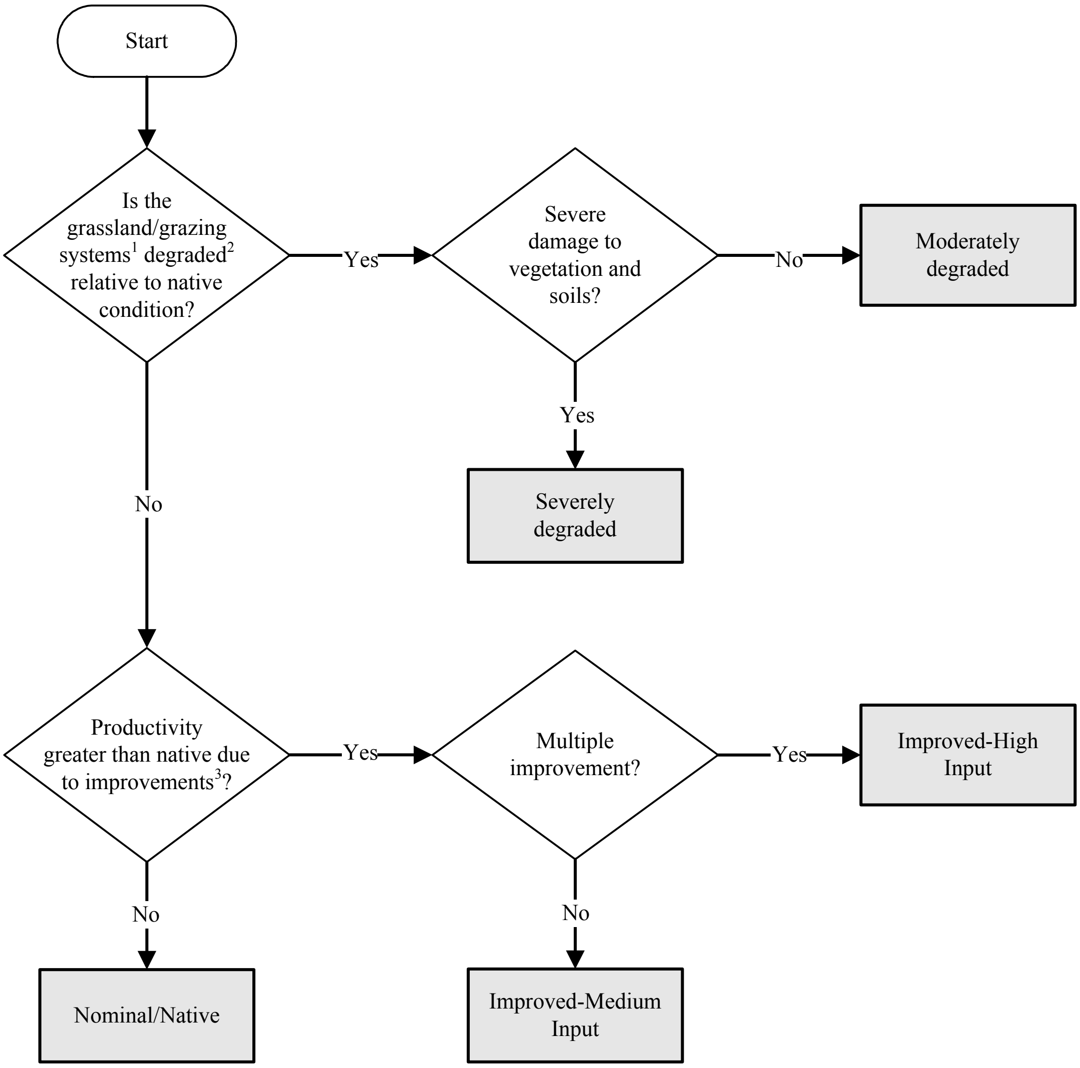
Grassland systems are classified by practices that influence soil C storage. In general, practices that are known to increase C input to the soil and thus soil organic C stocks, such as irrigation, fertilization, liming, organic amendments, more productive grass varieties, are given an improved status, with medium or high inputs depending on the level of improvement. Practices that decrease C input and soil organic C storage, such as long-term heavy grazing, are given a degraded status relative to nominally-managed seeded pastures or native grassland that are neither improved nor degraded. These practices are used to categorize management systems and then estimate the change in soil organic C stocks. A classification system is provided in Figure 6.1, which forms the basis for a Tier 1 inventory. 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.

The main types of land-use activity data include: 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 information on land-use conversion and explicit geo-referencing (Approach 3), such as point-based 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 statistics, such as FAO's databases (http://www.fao.org/waicent/portal/glossary_en.asp), provide annual compilations of total land area by major land-use types. This 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 stocking rates, fertilizer use, irrigation, etc. These data can also be aggregate statistics (Approach 1) or provide information on explicit management changes (Approach 2 or 3). It is *good practice* where possible for grassland areas to be assigned appropriate general management activities (i.e., degraded, native, or improved) or specific management activities (e.g., fertilization or grazing intensity). Soil degradation maps may be a useful source of information for stratifying grassland according to management (e.g., Conant and Paustian, 2002; McKeon *et al*., 2004). Expert knowledge is another source of information for management practices. It is *good practice* to elicit expert knowledge, where appropriate, using methods provided in Volume 1, Chapter 2 (Annex 2A.1, A protocol for expert elicitation).

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 pastoral and land-use statistics (Approach 1). Time series data can be more readily associated with a particular grassland management system and the soil type associated with the particular location can be determined by sampling or by referencing the location to a suitable soil map. Inventory points 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).

Figure 6.1 Classification scheme for grassland/grazing systems. In order to classify grassland 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 6.2.



Note:
1: Includes continuous pasture, hay lands and rangelands.
2: Degradation is equated with C input to the soil relative to native conditions, which may be caused by long-term heavy grazing or planting less productive plants relative to native vegetation.
3: Productivity refers explicitly to C input to soil (management improvements that increase input e.g., fertilization, organic amendment, irrigation, planting more productive varieties, liming, and seeding legumes).

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 maps of national origin or global sources, such as the FAO Soils Map of the World and climate data from the United Nations Environmental Program. A detailed description of the default climate and soil classification schemes is provided in Chapter 3, Annex 3A.5. The soil classification is based on soil taxonomic description and textural data, while climate regions are based on mean annual temperatures and precipitation, elevation, occurrence of frost, and potential evapotranspiration.

Tier 2

Tier 2 approaches are likely to involve a more detailed stratification of management systems (Figure 6.1) than in Tier 1, if sufficient data are available. This could include further subdivisions of grassland systems (i.e., moderately degraded, severely degraded, nominal and improved), and the input classes (medium and high input). 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 could involve a finer stratification of climate regions and soil types.

Tier 3

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

Organic soils

Tier 1

In contrast to the mineral soil method, grasslands on organic soils are not classified into management systems under the assumption that drainage stimulates oxidation of organic matter at about the same rate after exposure to aerobic conditions, regardless of the management system. However, in order to apply the method described in Section 2.3.3.1 (Chapter 2), managed grasslands do need to be stratified by soil type and climate region (see Chapter 3, Annex 3A.5, for guidance on soil and climate classifications).

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

Tier 2

Tier 2 approaches may involve a stratification of management systems if sufficient data are available. This could include a division of grassland systems by drainage class, for example. Tier 2 approaches could also involve a finer stratification of climate regions.

Tier 3

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

6.2.3.4 CALCULATION STEPS FOR TIER 1

Mineral soils

The steps for estimating SOC_0 and $SOC_{(0-T)}$ and net soil C stock change from *Grassland Remaining Grassland* are as follows:

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

Step 2: Determine the land-use and management by mineral soil type and climate region for land at the beginning of the inventory period, which can vary depending on the time step of the activity data (0-T; e.g., 5, 10 or 20 years ago).

Step 3: Select the native reference C stock value (SOC_{REF}), based on climate and soil type from Table 2.3, for each area of land being inventoried. The reference C stocks are the same for all land-use categories to ensure that erroneous changes in the C stocks are not computed due to differences in reference stock values among sectors.

Step 4: Select the land-use factor (F_{LU}), management factor (F_{MG}) and C input levels (F_I) representing the land-use and management system present at the beginning of the inventory period. Values for F_{LU}, F_{MG} and F_I are provided in Table 6.2.

Step 5: Multiply these values by the reference soil C stock to estimate the 'initial' soil organic C stock ($SOC_{(0-T)}$) for the inventory time period.

Step 6: Estimate SOC_0 by repeating Step 1 to 4 using the same native reference C stock (SOC_{REF}), but with land-use, management and input factors that represent conditions in the last (year 0) inventory year.

Step 7: Estimate the average annual change in soil organic C stock for the area over the inventory time period ($\Delta C_{Mineral}$).

Step 8: Repeat Steps 1 to 6 if there are additional inventory time periods (e.g., 1995 to 2000, 2001 to 2005, etc.).

A case example is given below for computing a change in grassland soil organic C stocks using Equation 2.25 (Chapter 2), default stock change factors and reference C stocks.

Example: The following example shows calculations for aggregate areas of grassland soil carbon stock change to a 30 cm depth. In a tropical moist climate on Ultisol soils, there are 1Mha of permanent grassland. The native reference carbon stock (SOC_{Ref}) for the climate/soil type is 47 tonnes C ha^{-1}. At the beginning of the inventory time period (1990 in this example) the distribution of grassland systems was 500,000 ha of unmanaged native grassland; 400,000 ha of unimproved, moderately degraded grazing land; and 100,000 ha of heavily degraded grassland. Thus, initial soil carbon stocks for the area were: 500,000 ha ● (47 tonnes C ha^{-1} ● 1 ● 1 ● 1) + 400,000 ha ● (47 tonnes C ha^{-1} ● 1 ● 0.97 ● 1) + 100,000 ● (47 tonnes C ha^{-1} ● 1 ● 0.7 ● 1) = 45,026,000 tonnes C. In the last year of inventory time period (2010 in this example), there are: 300,000 ha of unmanaged native grassland; 300,000 ha of unimproved, moderately degraded grazing land; 200,000 ha of heavily degraded grassland; 100,000 ha of improved pasture receiving fertilizer; and 100,000 of highly improved pasture receiving fertiliser together with irrigation. Thus, total soil carbon stocks in the inventory year are: 300,000 ha • (47 tonnes C ha^{-1} ● 1 ● 1 ● 1) + 300,000 ha ● (47 tonnes C ha^{-1} ● 1 ● 0.97 ● 1) + 200,000 ● (47 tonnes C ha^{-1} 1 ● 0.7 ● 1) + 100,000 ● (47 tonnes C ha^{-1} 1 ● 1.17 ● 1) + 100,000 ● (47 tonnes C ha^{-1} ● 1 ● 1.17 ● 1.11) = 45,959,890 tonnes C. The average annual stock change over the period for the entire area is: 45,959,890 – 45,026,000 = 933,890 tonnes/20 yr = 46,694.5 tonnes per year soil C stock increase. (Note: 20 years is the time dependence of the stock change factor, i.e., factor represents annual rate of change over 20 years).

Organic soils

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

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

Step 2: Determine the amount of *Grassland Remaining Grassland* on drained organic soils in the last year of each inventory time period.

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

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

Step 5: Repeat for additional inventory time periods.

6.2.3.5 UNCERTAINTY ASSESSMENT

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

For Tier 1, uncertainties are provided with the reference C stocks in the first footnote in Table 2.3, emission factors for organic soils in Table 6.3, and stock change factors in Table 6.2. Uncertainties in land-use and management data will need to be addressed by the inventory compiler, and then combined with uncertainties for the default factors and reference C stocks (mineral soils only) using an appropriate method, such as simple error propagation equations. If using aggregate land-use area statistics for activity data (e.g., FAO data), the inventory agency may have to apply a default level of uncertainty for the land area estimates (±50%). However, it is *good practice* for the inventory compiler to derive uncertainties from country-specific activity data instead of using a default level.

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

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

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

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

6.2.4 Non-CO_2 greenhouse gas emissions from biomass burning

Non-CO_2 emissions from biomass burning in *Grassland Remaining Grassland* result predominantly from `savannah burning`, which occurs mostly in tropical and sub-tropical regions. However, grassy and woody formations elsewhere in the world can also be subject to fire, mainly as a result of management practices, and the resulting non-CO_2 emissions should also be reported.

CO_2 emissions from biomass burning in *Grassland Remaining Grassland* are not reported since they are largely balanced by the CO_2 that is reincorporated back into biomass via photosynthetic activity, within weeks to few years after burning.

Non-CO_2 emissions (particularly CO, CH_4, N_2O and NO_x) that result from incomplete combustion of biomass in managed grassland should be reported, regardless of their nature (natural or anthropogenic fire). The amount of biomass burnt in any one fire may change from region to region, as well as vary seasonally. The efficiency of combustion and the corresponding fraction of the biomass converted into non-CO_2 greenhouse gases may also vary.

Countries should report non-CO_2 emissions from biomass burning in *Grassland Remaining Grassland* using annual data, instead of an average of activity data for a given period. This allows the reporting to capture interannual fluctuations due to climatic events (such as El Niño), or natural climatic variability (unusually dry years, when disturbances from fire may be more frequent). Generally, the estimates are highly uncertain due to the lack of reliable and accurate data on the mass of fuel available for combustion, and combustion and emission factors.

The general method for estimating greenhouse gas emissions in *Grassland Remaining Grassland* is described in Equation 2.27 in Chapter 2. Emissions from biomass burning should be estimated from the above-ground biomass, and DOM pools. With burning, below-ground biomass is assumed to remain constant after disturbance, or transferred to the soil pool. Default values for Tier 1 method or components of a Tier 2 method are provided in Section 2.4 of Chapter 2.

6.2.4.1 CHOICE OF METHOD

Figure 2.6 in Chapter 2 presents a decision tree that guides the selection of the appropriate Tier level to report non-CO_2 emissions from biomass burning. If biomass burning in *Grassland Remaining Grassland* is not a key category, countries may choose to report non-CO_2 emissions using Tier 1 method, which is based on highly aggregated data and default combustion and emission factors. However, if biomass burning in *Grassland Remaining Grassland* is a key category, countries should strive for improving inventory and reporting approaches by applying the highest Tier possible, given national circumstances.

Tier 1

Equation 2.27 should be applied when choosing to report under a Tier 1 method. Tier 1 is based on highly aggregated data and default combustion and emission factors. If data on *Mass of Fuel Available for Combustion* (M_B) are not available, countries should use the default data in Table 2.4 in Chapter 2 for the mass of fuel consumed. However, since the data in this table is provided by vegetation types and sub-categories, countries applying these default data should stratify the area of *Grassland Remaining Grassland* in their territory before choosing the appropriate default value (or values) to be applied.

Tier 2

Tier 2 extends Tier 1 by incorporating more disaggregated area estimates (per vegetation types, sub-categories) and country-specific estimates of combustion and emission factors for each stratum. The area burnt can be estimated using remotely sensed data of adequate spatial and temporal resolutions analysed according to a robust sampling design. The periodicity of data acquisition is crucial especially in the tropics, where burning occurs during a specific period in the year, which can extend over several months. It is important, when estimating the area burnt, to capture the month-to-month variation of the area burnt.

Tier 3

Tier 3 method should be based on models with algorithms to generate regional scale maps of area burnt using satellite data of multiple sources and of moderate spatial resolution. The results should be validated using high spatial resolution data augmented by field observations, and refined based on the validation results and feedback from operational users. A sampling approach can be designed to generate estimates of area burnt. Countries should stratify, as far as possible, the *Grassland Remaining Grassland* areas, and the corresponding combustion and emission factors. The Tier 3 method should provide estimates (fluxes) of the impact of biomass burning on all pools, including below-ground biomass.

6.2.4.2 CHOICE OF EMISSION FACTORS

Tier 1

Under a Tier 1 approach, default values are provided for combustion factors [fraction of fuel (above-ground biomass, litter and dead wood) consumed] in Table 2.6 in Chapter 2; and for emission factors in Table 2.5 in Chapter 2, for each non-CO_2 greenhouse gas. Estimates of above-ground biomass in savannas are provided in Table 6.4. The value in Table 2.4 should be used as the "fraction of fuel actually burnt" in Equation 2.27 in Chapter 2. Even though data for Tier 1 is usually highly aggregated, countries should seek to stratify the grassland area affected by biomass burning by broad vegetation type (shrubland, savanna woodland, savannah grassland), as well as according to the period of the burn (early dry season, or mid/late dry season). If the grassland is stratified by vegetation type and sub-category (e.g., savanna parkland, savanna woodland), countries can use the default values on biomass consumption provided in Table 2.4 in Chapter 2, which gives estimates of the product between fuel available and the fraction of biomass actually burnt (equivalent to the product of quantities M_B and C_f in Equation 2.27 in Chapter 2).

Tier 2

Countries using a Tier 2 approach should use country-specific combustion and emission factors developed for each broad grassland type (shrublands, savanna woodlands, savanna grassland) and sub-categories (if applicable).

Tier 3

Countries using a Tier 3 method should develop algorithms to estimate the area burnt, validating the products obtained with data from field observation and consultation with the product users.

6.2.4.3 CHOICE OF ACTIVITY DATA

Tier 1

For a Tier 1 method, the only activity data needed is the area affected by biomass burning in *Grassland Remaining Grassland*. If national data on burnt areas are not available, data from global fire maps can be used. However, note that any global fire product only represents a fraction of the total fires which take place both in time and space, due to inherent limitations of satellite sensors, which are the sources of the global map data. Alternatively, countries may also estimate the annual area burnt by multiplying the area of grassland in the territory by the estimated annual fraction of grassland burnt, and to apportion the area thus estimated between *Grassland Remaining Grassland* and *Grassland* converted to other land use.

Tier 2

This approach extends Tier 1 by incorporating more disaggregated data on areas affected by biomass burning. The grassland areas should be stratified according to different grassland vegetation types (shrublands, savanna grassland, savanna woodland, etc.) and by sub-category. National estimates of the area burnt should be produced. In the absence of reliable national data, countries can rely on global fire maps, but should strive to assess the particular sampling underlying the production of the fire maps, and, more importantly, whether the particular sample which is observed is affected by any systematic or unsystematic bias. Different data sources, which in general have different sampling strategies, should be used to estimate the total area burnt. Additionally, the burnt area should be compared to burnt areas with validation data sets.

Tier 3

Tier 3 requires high-resolution activity data disaggregated at sub-national to fine grid scales. Similar to Tier 2, the grassland area should be stratified by specific vegetation types and sub-categories to be used in models. If possible, spatially explicit area estimates are used to facilitate complete coverage of the grassland and ensure that areas are not over- or underestimated. Furthermore, spatially explicit area estimates can be related to locally relevant emission and combustion rates, improving the accuracy of estimates. The use of process-based models should provide a more accurate estimate of area burnt if the results are validated with field measurements. Sufficient representative measurements are needed for validation purposes.

6.2.4.4 UNCERTAINTY ASSESSMENT

There are several sources of uncertainty related to estimates of non-CO_2 emissions from biomass burning in *Grassland Remaining Grassland.* For example, savannas include a heterogeneous mosaic of grass, brush, thorn scrub, and open woodland. Fire behaviour varies greatly among these and hence, disaggregation of vegetative formations will lead to greater precision.

The fraction of fuel that is actually combusted during biomass burning (combustion factor) varies greatly, not only between ecosystems, but also between fires, between years, and as a function of cultural practices. Measurements from a given fire, year, and/or cultural setting cannot be extrapolated with confidence to other regions or years, or to biome scale (Robinson, 1989).

A major cause of uncertainty in estimating the contribution of biomass burning to emissions of trace gases is the extent of area burnt, intensity of the fire, and the rate of spread, especially in tropical ecosystems (Seiler and Crutzen, 1980; Matson and Ojima, 1990; Robinson, 1989). Precision estimates vary widely and depend essentially on the accuracy of the estimates of area burnt, proportion of the available fuel oxidized, and the biomass fuel available. Uncertainties of estimates of areas burnt can vary markedly depending on the methodology employed – for example, where very high resolution remote-sensing is used it may be of the order of 20%, whereas the use of global fire maps may result in uncertainties of up to two-fold. Uncertainties in estimates of greenhouse gas emissions over large regions from fire are likely to be at least 50%, even with good country-specific data, and at least two-fold where only default data are used.

6.3 LAND CONVERTED TO GRASSLAND

Land Converted to Grassland includes Forest Land or other land-use categories converted to Grassland within the last 20 years. Greenhouse gas inventory for the land-use category *Land Converted to Grassland* (LG) involves estimation of changes in carbon stock from five carbon pools (i.e., above-ground biomass, below-ground biomass, dead wood, litter, and soil organic matter), as well as emissions of non-CO_2 gases. The principal sources of emissions and removals of greenhouse gases in this category are associated with land-use change and management.

The carbon implications of the conversion from other land uses (mostly Forest Land, Cropland, and to lesser degree Wetlands and seldom Settlements) to Grassland is less clear cut than the case of conversion to Cropland. Literature on the main conversion type (from Forest Land to Grassland in the tropics) provides evidence for net gains as well as net losses in soil carbon, and the effect of management on the soil carbon changes of grassland after conversion is critical (see, for example, Veldkamp, 2001) as well as the pre-conversion stocks. Conversion of land from other uses and from natural states to Grassland can result in net emissions or net uptake of CO_2 from both, biomass and soil. The conversion process may also result in emissions from biomass burning.

The decision tree in, Figure 1.3 (Chapter 1) provides guidance for selecting the appropriate tier level for the implementation of estimation procedures for *Land Converted to Grassland*.

6.3.1 Biomass

This section provides guidelines for estimating carbon stock changes in biomass due to the conversion of unmanaged land to managed grassland, as well as conversion from other land uses to grassland, including *Forest Land Converted to Grassland* and Cropland converted to pasture and grazing lands. The changes in carbon stock in biomass from land conversion to grassland result from the removal of existing vegetation and replacement with grassland vegetation. This differs from the concepts underlying carbon stock changes in biomass of *Grassland Remaining Grassland* where changes are tied to management practices.

Conversion of land to grassland often results in the transfer of carbon from one pool to another. All transfers must be accounted for and gains and losses from these pools during the transition to a new steady state must be accounted when reporting lands converted to grasslands. For example, when converting a forest to a pasture, trees are felled and a portion of the above-ground biomass is transferred to the dead organic matter pool, a portion of the below-ground biomass is transferred to the soil organic matter pool, etc.

Estimating changes in carbon stocks in biomass for lands converted to grassland requires a two-phase approach. There is often an abrupt change in biomass associated with the land-use change, particularly when the change is deliberate and associated with land preparation operations (e.g., clearing and burning). This abrupt change is treated as Phase 1, and is estimated at the year of conversion. The second phase (Phase 2) accounts for gradual biomass loss and gain during a transition period to a new steady-state system. At some point in time, the grassland ecosystem should approach an equilibrium, when it is then considered under the category *Grassland Remaining Grassland* and accounted for under that category. A 20-year transition period following conversion is the default period for remaining in the transitional category, but countries can determine the appropriate transition period at their discretion. The values of coefficients determining the rate of emissions may depend on the transition period used.

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

It is likely that a number of lands converted to grassland will not have an abrupt transition (e.g., Cropland that is abandoned and that reverts to Grassland). In this case, Phase 1 methods will not be appropriate and there will be a gradual transition in biomass pools to a new equilibrium. When this type of conversion occurs, the whole conversion accounting can be treated with Phase 2 methods.

It is *good practice* to apportion transfers of carbon between pools when there is an abrupt transition. The immediate impacts of land conversion activities on the five carbon stocks can be summarized in a "disturbance matrix". The disturbance matrix describes the retention, transfers and releases of carbon in the pools in the original ecosystem following conversion to grassland. 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 the disturbance matrix in Table 2.1 in Chapter 2. If the rate of land conversion is more or less constant, the assumption that all carbon in theses pools was lost at the time of conversion would be a reasonable first approximation. Where the rate of land conversion varies over time, it is *good practice* to account for the transfer and release of carbon among the different carbon pools and ensure that all carbon is accounted.

In cases where there is an immediate and abrupt carbon stock change in biomass due to conversion to grasslands, the effect of this conversion will be estimated using Equation 2.16 in Chapter 2. During the transition period, pools that gain or lose C often have a non-linear loss or accumulation curve that can be represented through successive transition matrices. If the true shapes of the curves are known, these curves can be applied to each cohort that is under transition during the reporting year to estimate the annual emission or removal by the specific pool. If the shape of the curve is unknown, countries may simplify and use a linear decay function to estimate pool changes. Two methods are available to estimate these changes.

6.3.1.1 CHOICE OF METHOD

The decision tree in, Figure 2.2 (Chapter 2) provides guidance for selecting the appropriate tier level for the implementation of estimation procedures for biomass in *Land Converted to Grassland*. Estimation of changes in biomass requires an estimate of changes in above-ground vegetation and changes in below-ground biomass. Countries should use the highest tier possible given national circumstances. It is *good practice* to use a Tier 2 or Tier 3 approach if carbon emissions and removals in *Land Converted to Grassland* is a key category and if the sub-category of biomass is considered significant, based on principles outlined in Volume 1, Chapter 4 (Methodological Choice and Identification of Key Categories).

Tier 1

The change in biomass carbon stock on *Land Converted to Grassland* under Tier 1 should be estimated using Equation 2.15. 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 biomass growth following conversion. As a simplification for Tier 1, it is assumed that all biomass is lost immediately from the previous ecosystem after conversion (Equation 2.16) , even when there is no abrupt change, and residual biomass (B_{AFTER}) is thus assumed to be zero, (i.e., the land is cleared of all vegetation before grassland vegetation is established). Thus, there is no transfer of biomass from the biomass pool to the dead wood pool, for example. Default values for biomass prior to conversion can be found in the chapters relating to the respective land uses (e.g., default factors for Forest Land are to be found in the chapter dealing with biomass in Forest Land).

Additionally, it is assumed that grasslands achieve their steady-state biomass during the first year following conversion. Thus, for Tier 1, there are no stock changes associated with Phase 2, though the lands converted to grasslands should be retained in the conversion category for the 20 year transition period because the soil stocks will take longer to reach equilibrium. Emissions and uptakes from biomass during Phase 2 of the calculation are therefore zero. If there are significant management changes during the transition phase, countries can account for the impacts of this on C stocks in biomass using Tier 2 methods from *Grassland Remaining Grassland*. It is *good practice* to account for all *Land Converted to Grassland*. Thus, a separate calculation must be done for each type of conversion.

Tier 2

The Tier 2 calculations differ structurally in a number of ways from Tier 1. First, Tier 2 estimates use the two-phase approach described earlier. Tier 2 relies on some country-specific estimates of the biomass in initial and final land uses rather than the defaults, as in Tier 1. Area estimates for *Land Converted to Grassland* are disaggregated at higher resolution spatial scales than in Tier 1 to capture regional variations within the grassland formations of the country.

Second, for Tier 2 countries may modify the assumption that biomass immediately following conversion is zero. This enables countries to take into account land-use transitions where some, but not all, vegetation from the original land use is removed. In addition, under Tier 2, it is possible to account for biomass accumulation following grassland establishment over a several year period (rather than accounting all biomass stock change in the year of conversion) if data are available to estimate the time to full biomass establishment and the annual stock changes.

Third, under Tier 2, it is *good practice* to apportion transfers of carbon between pools. Grassland systems typically do not contain significant carbon in the dead wood or litter pools, but dead wood may persist for a number of years in young grasslands that are replacing forests or accumulate in scrublands as woody biomass senesces. If the rate of land conversion is more or less constant, the assumption that all carbon in theses pools was lost at the time of conversion would be a reasonable first approximation. Where the rate of land conversion varies over time, it is appropriate to try to account for the transfer and release of carbon from litter, dead wood, and soil carbon pools. It is therefore necessary to distinguish immediate losses due to the conversion activities from the losses that occur in the years following the land conversion.

The immediate and abrupt carbon stock change in biomass due to *Land Converted to Grassland* under Tiers 2 and 3 will be estimated using Equation 2.16 in Chapter 2, where B_{AFTER} is assumed to be zero. During the transition period, pools that gain or loose C often have a non-linear loss or accumulation curve that can be represented through successive transition matrices. For Tier 2, a linear change function can be assumed. For a Tier 3 approach based upon these methods, it is *good practice* to use the true shapes of the curves. These curves are to be applied to each cohort that is under transition during the reporting year to estimate the annual change in the biomass carbon pools.

For the estimation of changes in biomass carbon during the transition phase, two methods are suggested. The equations used are the same as those used for Tier 2 in *Grassland Remaining Grassland* section.

Gain-Loss Method *(see Equation 2.7 in Chapter 2):* This method involves estimating the area of each type of land conversion and the average annual transfer into and out of biomass stocks. This requires: (i) an estimate of the area under *Land Converted to Grassland* according to different climate or ecological zones or grassland types, disturbance regime, management regime, or other factors significantly affecting biomass carbon pools; (ii) the quantity of biomass accumulating in the biomass stocks; and (iii) the quantity of biomass lost from the biomass stocks on per hectare basis according to different grassland types.

Stock-Difference Method *(see Equation 2.8 in Chapter2):* This method involves estimating the area of *Land Converted to Grassland* and the biomass stocks at two periods of time, t_1 and t_2. The biomass stock changes for the inventory year are obtained by dividing the stock changes by the period (years) between two measurements. The Stock-Difference Method is feasible for countries that have periodic inventories, and is more suitable for countries adopting Tier 3 methods. This method may not be well suited to regions with very variable climates and may produce spurious results unless annual inventories can be made.

Tier 3

Tier 3 methods are used where countries have country-specific emission factors, and substantial national data. Country-defined methodology may be based on detailed inventories of permanent sample plots for their grasslands and/or models. For Tier 3, countries should develop their own methodologies and parameters for estimating changes in biomass. These methodologies may be derived from methods specified above, or may be based on other approaches. The method used needs to be clearly documented.

Tier 3 involves inventory systems using statistically-based sampling of biomass over time and/or process models, stratified by climate, grassland type and management regime. For example, validated species-specific growth models that incorporate management effects such as grazing intensity, fire, liming, and fertilization, with corresponding data on management activities, could be used to estimate net changes in grassland biomass over time. Models, together with periodic sampling-based biomass estimates, similar to those used in detailed forest inventories, could be applied to estimate stock changes to make spatial extrapolations for grassland areas.

Key criteria in selecting appropriate models include the ability to represent all of the ecosystem conversions and 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 the variability of climate, soil and grassland management systems in the country.

If possible, spatially explicit area estimates should be used to facilitate complete coverage of the grassland and ensure that areas are not over- or underestimated. Furthermore, spatially explicit area estimates can be related to locally relevant carbon accumulation and removal rates, and restocking and management impacts, improving the accuracy of estimates.

6.3.1.2 CHOICE OF EMISSION/REMOVAL FACTORS

Tier 1

Tier 1 methods require estimates of the biomass of the land use before conversion and after conversion. It is assumed that all biomass is cleared when preparing a site for grassland use, thus, the default for biomass immediately after conversion is 0 tonne ha^{-1}. Default values for biomass can be found at:

- Forest Land prior to clearing: see Chapter 4 (Forest Land);
- For Cropland containing woody perennial crops: see Chapter 5 (Cropland); and
- For Cropland containing annual crops: Use default of 4.7 tonnes of carbon ha^{-1} or 10 tonnes of dry matter ha^{-1}. The error range associated with this default is ±75%.

Table 6.4 provides default values for biomass following conversion; however, there is wide variation within any region largely driven by rainfall and soil texture. These default values have high error rates and thus when better country-specific data are available, countries should use the best locally available data to estimate grassland biomass.

TABLE 6.4
DEFAULT BIOMASS STOCKS PRESENT ON GRASSLAND , AFTER CONVERSION FROM OTHER LAND USE

IPCC climate zone	Peak above-ground biomass[1] (tonnes d.m. ha^{-1})	Total (above-ground and below-ground) non-woody biomass[2] (tonnes d.m. ha^{-1})	Error [3]
Boreal – Dry & Wet[4]	1.7	8.5	± 75%
Cold Temperate – Dry	1.7	6.5	± 75%
Cold Temperate –Wet	2.4	13.6	± 75%
Warm Temperate – Dry	1.6	6.1	± 75%
Warm Temperate –Wet	2.7	13.5	± 75%
Tropical – Dry	2.3	8.7	± 75%
Tropical - Moist & Wet	6.2	16.1	± 75%

[1] Data for standing biomass are compiled from multi-year averages reported at grassland sites registered in the ORNL DAAC NPP database [http://www.daacsti.ornl.gov/NPP/].

[2] Total above-ground and below-ground biomass values are based on the peak above-ground biomass values, and the below-ground biomass to aboveground biomass ratios (Table 6.1).

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

[4] Due to limited data, dry and moist zones for the boreal temperature regime and moist and wet zones for the tropical temperature regime were combined.

Tier 2

It is *good practice* to use country-specific estimates for biomass stocks and emissions/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 grassland. 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 or region and a re-examination of default assumptions in light of country-specific conditions.

Region-specific or country-specific data on biomass for young grasslands are needed for a Tier 2 approach. These can be obtained through a variety of methods, including estimating density (e.g., crown cover) of woody and herbaceous 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 grassland types and conditions and thus it may be most efficient to stratify sampling and survey activities by grassland types. General guidance on survey and sampling techniques for biomass inventories is given in Chapter 3 in Annex 3A.3.

Accurately capturing the dynamics of below-ground biomass is necessary for accounting for carbon stock changes when land is converted to grassland. In the case of abandonment of Cropland, below-ground biomass will increase continuously as ecosystem succession takes place. For lands converted from forest to pasture, there will be a gradual decomposition of below-ground forest biomass and a gradual increase of below-ground biomass of pasture grasses. Estimating below-ground biomass can be an important component of biomass surveys of grassland but field measurements are laborious and difficult and thus expansion factors to estimate below-ground biomass from above-ground biomass are often used.

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*).* Thus, it is recommended to use, as far as possible, empirically-derived root-to-shoot ratios specific to a region or vegetation type. Table 6.1 provides default root-to-shoot ratios for major grassland ecosystems of the world; these data can be used as defaults when countries do not have more regionally specific information to develop country-specific ratios. Ratios for woodland/savannah and scrublands are also included for use by countries that include these lands in the grassland section of their inventory.

Tier 3

Tier 3 approaches consist of using a combination of dynamic models and inventory measurements of biomass stock changes. This approach does not employ simple stock changes or emission factors *per se*. Estimates of emissions/removals using model-based approaches are derived from the interaction of multiple equations that estimate the net change of biomass stocks within the models. Models can be used, together with periodic sampling-based stock estimates similar to those used in detailed forest inventories, to estimate stock changes or inputs and outputs (as in Tier 2 to make spatial extrapolations for grassland areas). For example, validated species-specific growth models that incorporate management effects such as grazing intensity, fire, and fertilization, with corresponding data on management activities, could be used to estimate net changes in grassland biomass over time.

6.3.1.3 CHOICE OF ACTIVITY DATA

All tiers require estimates of land areas converted to Grassland. The same area data should be used for biomass calculations, dead organic matter, and the soil carbon estimates. If necessary, area data used in the soils analysis can be aggregated to match the spatial scale required for lower order estimates of biomass; however, at higher tiers, stratification should take account of major soil types. Area data should be obtained using the methods described in Chapter 3. Cross-checks should be made to ensure complete and consistent representation of annually converted lands in order to avoid possible omissions or double counting. Data should be disaggregated according to the general climatic categories and grassland types. Tier 3 inventories will require more comprehensive information on the establishment of new grasslands, with refined soil classes, climates, and spatial and temporal resolution. All changes having occurred over the number of years selected as the transition period should be included with transitions older than the transition period (default 20 years) reported as a subdivision of *Grassland Remaining Grassland*. Higher tiers require greater detail but the minimum requirement for inventories to be consistent with the *IPCC Guidelines* is that the areas of forest conversion are identified separately. This is because forest will usually have higher carbon density before conversion. This implies that at least partial knowledge of the land-use change matrix, and therefore, where Approaches 1 and 2 from Chapter 3 are used to estimate land area are being used, supplementary surveys may be needed to identify the area of land being converted from Forest Land to Grassland. As pointed out in Chapter 3, where surveys are being set up, it will often be more accurate to seek to establish directly areas undergoing conversion than to estimate these from the differences in total land areas under particular uses at different times.

Tier 1

Estimates of areas converted to Grassland, from initial land uses (i.e., Forest Land, Cropland, Settlements, etc.) to final grassland type, are necessary. The methodology assumes that area estimates are based on a one-year time frame, after which they are transferred to the category *Grassland Remaining Grassland*. If area estimates are assessed over longer time frames, they should be converted to average annual areas to match the carbon stock values used. 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. At a minimum, countries can rely on average deforestation rates and land-use conversions to grassland from international sources, including the FAO (See FAOSTAT website). Tier 1 approaches may use average annual rates of conversion and estimated areas in place of direct estimates.

Tier 2

It is *good practice* to use actual area estimates for all possible transitions from initial land use to final grassland type. Complete reporting can be accomplished either through analysis of periodic remotely sensed images of land-use and land-cover patterns, and/or periodic ground-based sampling of land-use patterns, or hybrid inventory systems.

Tier 3

Activity data used in Tier 3 calculations should provide a full accounting of all land-use transitions to grassland and be disaggregated to account for different conditions within a country. Disaggregation can occur along political boundaries (county, province, etc.), biome area, climate zone, or on a combination of these parameters. In many cases countries may have information on multi-year trends in land conversion (from periodic sample-based or remotely sensed inventories of land use and land cover).

6.3.1.4 CALCULATION STEPS FOR TIERS 1 AND 2

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

Worksheets have been provided for completing Tier 1 estimates of emissions and removals from this category (see Annex 1 AFOLU Worksheets). For this calculation, Equation 2.15 is simplified. The assumption for Tier 1 is that ΔC_G and ΔC_L equal zero. Thus, the only term that requires calculation is the $\Delta C_{CONVERSION}$, which is calculated with Equation 2.16. For lands converted to Grassland, Equation 2.16 is computed twice, once for the herbaceous biomass and once for the woody biomass. This is done because each of these components has a different carbon fraction.

Tier 1

For Tier 1, only the abrupt change needs to be calculated. The simplifying assumption is that all stock changes occur in the year of conversion. Thus for conversions older than 1 year, but still in the transition period, the assumption is that there are no net changes in biomass C stocks.

Step 1: Determine the categories of land conversion to be used in this assessment and the representative areas. Tier 1 requires estimates of areas converted to Grassland, from initial land uses (i.e., Forest Land, Cropland, Settlements, etc.) to final grassland type. When calculating for lands in the transition phase, only the total area of land converted during the previous 20 years is required as the Tier 1 assumption is that all changes in C stocks in the biomass occur during the first year.

Step 2: Determine the activity categories to be used in this assessment and the representative areas. The activity category consists of definitions of the type of conversion and, if applicable, the nature of management of the previous land cover and grassland management (e.g., 'conversion of logged tropical seasonal forest to cattle pasture using exotic grasses').

Step 3: For each activity category, determine the biomass per hectare in herbaceous biomass and woody biomass (separately) prior to conversion. Where data on below-ground biomass are lacking, use below-ground to above-ground biomass ratios to estimate the below-ground component of the biomass. Default values can be found in the chapter that refers to the other land-use category.

Step 4: For each activity category, determine the biomass per hectare in herbaceous biomass and woody biomass (separately) following one year of conversion to grassland. Where data on below-ground biomass are lacking, use below-ground to above-ground biomass ratios to estimate the below-ground component of the biomass. Default values for herbaceous biomass can be found in Table 6.4.

Step 5: Determine the appropriate carbon fractions for herbaceous and woody biomass. The default values are 0.50 tonne C (tonne d.m.)$^{-1}$ for woody biomass and 0.47 tonne C (tonne d.m.)$^{-1}$ for herbaceous biomass.

Step 6: Estimate the net change of carbon stocks in woody and herbaceous biomass (separately) by subtracting the final biomass from the initial biomass and multiplying this difference by the representative area for the activity and by the carbon fraction of the biomass component. A negative value indicates an increase of biomass.

Step 7: Sum the changes in carbon stocks in woody and herbaceous biomass to determine the net change in biomass C stocks for each activity category. Sub-totals for each type of conversion should be computed and a grand total should be computed and entered at the bottom of the last column of the table.

Tier 2

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

Step 2: Abrupt changes

- Determine the activity categories to be used in this assessment and the representative areas. The activity category consists of definitions of the type of conversion and, if applicable, the nature of management of the previous land cover and grassland management (e.g., 'conversion of logged tropical seasonal forest to cattle pasture using exotic grasses').

- For each activity category, determine the biomass per hectare in herbaceous biomass and woody biomass (separately) prior to conversion. Where data on below-ground biomass are lacking, use below-ground to above-ground biomass ratios to estimate the below-ground component of the biomass.
- For each activity category, determine the biomass per hectare in herbaceous biomass and woody biomass (separately) following one year of conversion to grassland. Where data on below-ground biomass are lacking, use below-ground to above-ground biomass ratios to estimate the below-ground component of the biomass.
- Determine the appropriate carbon fractions for herbaceous and woody biomass. The default values are 0.50 tonne C (tonne d.m.)$^{-1}$ for woody biomass and 0.47 tonne C (tonne d.m.)$^{-1}$ for herbaceous biomass.
- Estimate the net change of woody and herbaceous biomass per hectare for each type of conversion by subtracting the final biomass from the initial biomass and multiplying this difference by the representative area for the activity and by the carbon fraction of the biomass component. A negative value indicates an increase of biomass.
- Sum the changes in carbon stocks in woody and herbaceous biomass to determine the net change in biomass C stocks for each activity category. Sub-totals for each type of conversion should be computed and a grand total should be computed.

Step 3: Transitional changes

- Determine the categories and cohorts to be used in this assessment and the representative areas. The category consists of definitions of the type of conversion and, if applicable, the nature of management of the previous land cover and grassland management (e.g., 'conversion of logged tropical seasonal forest to cattle pasture using exotic grasses').
- Determine the annual change rate for herbaceous and woody biomass (separately) by activity type using either the Gain-Loss Method or the Stock-Difference method (see below) for each cohort of lands that are currently in the transition phase between conversion and a new steady-state grassland system.
- Determine the herbaceous and woody biomass in the cohort during the previous year (usually taken from the previous inventory).
- Estimate the change in herbaceous and woody biomass for each cohort by adding the net change rate to the previous year's stocks.

Gain-Loss Method (Equation 2.7 in Chapter 2)

- Determine the average annual increment of herbaceous and woody biomass (separately).
- Determine the average annual losses of herbaceous and woody biomass (separately).
- Determine the net change rate in herbaceous and woody biomass by subtracting the loss from the increment.

Stock-Difference Method (Equation 2.8 in Chapter 2)

- Determine the inventory time interval, the average stocks of herbaceous and woody biomass at the initial inventory, and the average herbaceous and woody biomass at the final inventory.
- Use these figures to estimate the net annual difference in herbaceous and woody biomass by subtracting the initial stock from the final stock and dividing this difference by the number of years between inventories. A negative value indicates a loss in the stock.
- A Tier 2 approach requires country-specific or ecosystem-specific expansion factors and the best available local data should be used (and documented).

6.3.1.5 UNCERTAINTY ASSESSMENT

Uncertainty analyses for *Land Converted to Grassland* are fundamentally the same as *Grassland Remaining Grassland*. Two sources of uncertainty exist in C inventories: 1) uncertainties in land-use and management activity and environmental data; 2) uncertainties in carbon increase and loss, carbon stocks and expansion factor terms in the stock change/emission factors for Tier 2 approaches, model structure/parameter error for Tier 3 model-based approaches, or measurement error/sampling variability associated with Tier 3 measurement-based inventories. See the uncertainty section in *Grassland Remaining Grassland* for additional discussion (Section 6.2.1.5).

6.3.2 Dead organic matter

In this section, changes in carbon stocks of dead organic matter pool (DOM) are presented for the land category *Land Converted to Grassland*. Cropland, Forest Land, Settlements, and other land-use categories could be potentially converted to Grassland. Methods are provided for two types of dead organic matter pools: 1) dead wood, and 2) litter. Chapter 1of this Volume provides detailed definitions of these pools. The features of dead wood and litter are described in Section 6.2.2.

Estimating changes in carbon stocks in DOM for *Land Converted to Grassland* requires a two-phase approach, similar to approach described in Biomass Section (Section 6.3.1). During the first phase, there is often an abrupt change in DOM associated with the land-use change, particularly when the change is deliberate and associated with land preparation operations (e.g., clearing and burning). The second phase accounts for decay and accumulation processes during a transition period to a new steady-state system. At some point in time, the grassland ecosystem should reach an equilibrium; at which time it can be considered *Grassland Remaining Grassland* and accounted for under that category. A 20-year transition period following conversion is the default period, but countries are free to determine the appropriate transition period at their discretion.

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

It is likely that many land uses will not have a dead wood or a litter pool, so that corresponding carbon pools prior to conversion can be assumed to be zero. Forest Land, agroforests, and Wetlands converted to Grassland, could have significant carbon in these pools, as well as forest areas around settlements that may have been defined as settlements based on nearby use rather than land cover.

It is also likely that a number of land areas converted to grassland will not have an abrupt transition (e.g. Cropland that is abandoned and that reverts to grassland). In this case, Phase 1 assumptions will not be appropriate and there will be a gradual transition in DOM pools to a new equilibrium. When this type of conversion occurs, the whole conversion accounting can be treated as Phase 2.

Conversion of lands to grasslands often involves clearing and burning. As land is cleared, DOM may be removed for fuelwood or other uses. Countries may try to quantify these removals and account for the carbon in other sectors (e.g. Energy). Additionally, burning the remaining vegetation does not completely remove the DOM and some is converted to charcoal. At higher tiers, countries may wish to account for this transfer to a long-term storage pool.

6.3.2.1 CHOICE OF METHOD

The decision tree in Figure 2.3 in Chapter 2 provides assistance in the selection of the appropriate tier level for the implementation of estimation procedures. Estimation of changes in carbon stocks in DOM requires an estimate of changes in stocks of dead wood and changes in litter stocks. Each of the DOM pools (dead wood and litter) is to be treated separately, but the method for each pool is the same.

Tier 1

A Tier 1 approach involves estimating the area of each type of land conversion using only the major conversion categories (e.g., Forest Land to Grassland). The immediate and abrupt carbon stock change (Phase 1) in dead wood and litter due to conversion of other lands to Grassland under Tier 1 is estimated using Equation 2.23 where C_0 equals zero and T_{on} equals 1. The Tier 1 default assumes removal of all dead wood and litter during conversion and that there is no dead wood or litter that remains or accumulates in *Land Converted to Grassland*. Countries where this assumption is known to be false (e.g., where slash and burn agriculture is widely practiced) are encouraged to use a higher tier when accounting for lands converted to Grassland. Additionally, it should be assumed that grasslands achieve steady-state biomass during the first year following conversion. Thus, for Tier 1, there is no emissions or removals associated with Phase 2, though the lands converted to Grassland should be retained in the conversion category for the 20-year transition period because the soil stocks will take longer to reach equilibrium.

There are no default values available for dead wood or litter in most systems. For forests, there are no global default values for dead wood, but there are values for litter (Table 2.2 in Chapter 2). Countries should make best estimates and use local data from forestry and agricultural research institutes to provide best estimates of the dead wood and litter in the initial system prior to conversion.

Tier 2

Tier 2 approaches require greater disaggregation than that used in Tier 1. Activity data should be reported by ecological zone and management regimes.

As explained in the biomass section (Section 6.3.1), the immediate impacts of land conversion activities on the five carbon pools can be summarized in a "disturbance matrix". The disturbance matrix describes the retention, transfers and releases of carbon in the pools in the original ecosystem following conversion to Grassland. A disturbance matrix defines the proportion of the carbon stock that remains in that pool and the proportion that is transferred to other pools. A small number of transfers are possible, and are outlined in the disturbance matrix in Table 2.1 in Chapter 2. Use of a disturbance matrix ensures consistency of the accounting of all carbon pools.

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

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

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

Stock-Difference Method (Equation 2.19 in Chapter 2): The Stock-Difference Method involves estimating the area of *Land Converted to Grassland* and the dead wood and litter stocks at two periods of time, t_1 and t_2. The annual dead wood and litter stock changes for the inventory year are obtained by dividing the stock changes by the period (years) between two measurements. This method is feasible for countries, which have periodic inventories. This method may not be well suited to regions with very variable climates and may produce spurious results unless annual inventories can be made.

Tier 3

For Tier 3, countries should develop their own methodologies and parameters for estimating changes in DOM. These methodologies may be derived from either of the methods specified above, or may be based on other approaches. The method used needs to be clearly documented. The Stock-Difference Method described above may be suitable for countries adopting Tier 3 methods. Tier 3 methods are used where countries have country-specific emission factors, and substantial national data. Country-defined methodology may be based on detailed inventories of permanent sample plots for their grasslands and/or models.

6.3.2.2 CHOICE OF EMISSION/REMOVAL FACTORS

Carbon fraction: The carbon fraction of dead wood and litter is variable and depends on the stage of decomposition. Wood is much less variable than litter and a value of 0.50 tonne C (tonne d.m.)$^{-1}$ can be used for the carbon fraction. Litter values in grasslands range from 0.30 to 0.50 tonne C (tonne d.m.)$^{-1}$. When country-specific or ecosystem-specific data are not available, countries should use a carbon fraction value of 0.40 tonnes C (tonne d.m.)$^{-1}$.

Tier 1

For Tier 1, it is assumed that the dead wood and litter carbon stocks in lands converted to grasslands are all lost during the conversion and that there is no accumulation of new DOM in the grassland after conversion. Countries experiencing significant conversions of other ecosystems to grasslands are encouraged to develop domestic data to quantify this impact and report it under Tier 2 or 3 methodologies.

Tier 2

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

Tier 3

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

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

6.3.2.3 CHOICE OF ACTIVITY DATA

All tiers require estimates of land areas converted to Grassland. The same area data should be used for biomass calculations, dead organic matter, and the soil carbon estimates. If necessary, area data used in the soils analysis can be aggregated to match the spatial scale required for lower order estimates of biomass; however, at higher tiers, stratification should take account of major soil types. Area data should be obtained using the methods described in Chapter 3. Cross-checks should be made to ensure complete and consistent representation of annually converted lands in order to avoid possible omissions or double counting. Data should be disaggregated according to the general climatic categories and grassland types. Tier 3 inventories will require more comprehensive information on the establishment of new grasslands, with refined soil classes, climates, and spatial and temporal resolution. All changes having occurred over the number of years selected as the transition period should be included with transitions older than the transition period (default 20 years) reported as a subdivision of *Grassland Remaining Grassland*. Higher tiers require greater detail but the minimum requirement for inventories to be consistent with the *IPCC Guidelines* is that the areas of forest conversion are identified separately. This is because forest will usually have higher carbon density before conversion. This implies that at least partial knowledge of the land-use change matrix, and therefore, where Approaches 1 and 2 from Chapter 3 are used to estimate land area are being used, supplementary surveys may be needed to identify the area of land being converted from Forest Land to Grassland. As pointed out in Chapter 3, where surveys are being set up, it will often be more accurate to seek to establish directly areas undergoing conversion, than to estimate these from the differences in total land areas under particular uses at different times.

Chapter 3 provides general guidance on approaches for obtaining and categorizing area by different land-use classes. For estimating emissions and removals from this source, countries need to obtain area estimates for conversions to grassland, disaggregated as required to correspond to the available emission factors and other parameters.

6.3.2.4 CALCULATION STEPS FOR TIERS 1 AND 2

For Tier 1, only the abrupt change needs to be calculated and this is done using Equation 2.23 where C_0 equals zero and T_{on} equals 1. The Tier 1 default assumes removal of all dead wood and litter during conversion and that there is no dead wood or litter that remains or accumulates in *Land Converted to Grassland*. Thus, for conversions older than 1 year but still in the transition period, the assumption is that there are no net changes in biomass C stocks.

Tier 1

Step 1: Determine the categories of land conversion to be used in this assessment and the representative areas. Tier 1 requires estimates of areas converted to Grassland from initial land uses (i.e., Forest Land, Cropland, Settlements, etc.) to final grassland type. When calculating for lands in the transition phase, only the total area of land converted during the previous 20 years is required as the Tier 1 assumption is that there is no accumulation of C stocks in the DOM during the first year. Note that all grasslands older than 20 years should be accounted for in *Grassland Remaining Grassland*. Thus, grassland areas that are 21 years old, must be transferred to this category.

Step 2: Determine the activity categories to be used in this assessment and the representative areas. The activity category consists of definitions of the type of conversion and, if applicable, the nature of management of the previous land cover and grassland management (e.g., 'conversion of logged tropical seasonal forest to cattle pasture using exotic grasses').

Step 3: For each activity category, determine the C stock per hectare in dead wood and litter (separately) prior to conversion. Default values, if they exist, can be found in the chapter that refers to the other land-use category.

Step 4: For each activity category, the C stock per hectare in dead wood and litter (separately) following one year of conversion to grassland is assumed to be 0.

Step 5: Determine the appropriate carbon fractions for dead wood and litter biomass. The default values are 0.50 tonne C (tonne d.m.)$^{-1}$ for dead wood and 0.40 tonne C (tonne d.m.)$^{-1}$ for litter.

Step 6: Estimate the net change of carbon stocks in dead wood and litter (separately) by subtracting the final stock from the initial stock and multiplying this difference by the representative area for the activity and by the carbon fraction of the biomass component.

Step 7: Sum the changes in carbon stocks in dead wood and litter to determine the net change in DOM C stocks for each activity category. Sub-totals for each type of conversion should be computed and a grand total should be computed and entered at the bottom of the last column of the table.

Tier 2

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

Step 2: Abrupt changes

- Determine the activity categories to be used in this assessment and the representative areas. The activity category consists of definitions of the type of conversion and, if applicable, the nature of management of the previous land cover and grassland management (e.g., 'conversion of logged tropical seasonal forest to cattle pasture using exotic grasses').
- For each activity category, determine the mass per hectare of dead wood and litter (separately) prior to conversion.
- For each activity category, determine the mass per hectare of dead wood and litter (separately) following one year of conversion to grassland.
- Determine the appropriate carbon fractions of dead wood and litter. The default values are 0.50 tonne C (tonne d.m.)$^{-1}$ for dead wood and 0.40 tonne C (tonne d.m.)$^{-1}$ for litter.
- Estimate the net change of C stock in dead wood and litter (separately) for each type of conversion by subtracting the final stocks from the initial stocks and multiplying this difference by the representative area for the activity and by the carbon fraction of the biomass component. A negative value indicates an increase of DOM.
- Sum the changes in carbon stocks in dead wood and litter to determine the net change in C stocks for each activity category. Sub-totals for each type of conversion should be computed and a grand total should be computed.

Step 3: Transitional changes

- Determine the categories and cohorts to be used in this assessment and the representative areas. The category consists of definitions of the type of conversion and, if applicable, the nature of management of the previous land cover and grassland management (e.g., 'conversion of logged tropical seasonal forest to cattle pasture using exotic grasses').
- Determine the annual change rate for dead wood and litter (separately) by activity type using either the Gain-Loss Method or the Stock-Difference Method (see below) for each cohort of lands that are currently in the transition phase between conversion and a new steady-state grassland system.
- Determine the dead wood and litter in the cohort during the previous year (usually taken from the previous inventory).
- Estimate the change in dead wood and litter for each cohort by adding the net change rate to the previous year's stocks.

Gain-Loss Method (Equation 2.18 in Chapter 2)

- Determine the average annual inputs of dead wood and litter (separately).
- Determine the average annual losses of dead wood and litter (separately).
- Determine the net change rate in dead wood and litter by subtracting the loss from the increment.

Stock-Difference Method (Equation 2.19 in Chapter 2)

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

6.3.2.5 UNCERTAINTY ASSESSMENT

Uncertainty analyses for *Land Converted to Grassland* are fundamentally the same as *Grassland Remaining Grassland*. Two sources of uncertainty exist in C inventories: 1) uncertainties in land-use and management activity and environmental data; 2) uncertainties in carbon increase and loss, carbon stocks and expansion factor terms in the stock change/emission factors for Tier 2 approaches, model structure/parameter error for Tier 3 model-based approaches, or measurement error/sampling variability associated with Tier 3 measurement-based inventories. See the uncertainty section in *Grassland Remaining Grassland* for additional discussion (Section 6.2.2.5).

6.3.3 Soil carbon

Grassland management involving drainage will generate emissions from organic soil, regardless of the previous land use. However, the impact on mineral soils is less clear-cut for lands converted to Grassland. Literature on one of the dominant conversion types globally (from Forest Land to Grassland in the tropics) provides evidence for net gains as well as net losses in soil C, and it is known that the specific management of the grassland after conversion is critical (e.g., Veldkamp, 2001).

General information and guidance for estimating changes in soil C stocks are provided in Chapter 2, Section 2.3.3 (including equations), and this section needs to be read before proceeding with a consideration of specific guidelines dealing with grassland soil C stocks. The total change in soil C stocks for *Land Converted to Grassland* is estimated using Equation 2.24 for the change in soil organic C stocks for mineral soils and organic soils; and stock changes associated with soil inorganic C pools (if estimated at Tier 3). This section provides specific guidance for estimating soil organic C stock changes. There is a general discussion in Section 2.3.3 in Chapter 2 on soil inorganic C and no additional information is provided here.

To account for changes in soil C stocks associated with *Land Converted to Grassland*, countries need to have, at a minimum, estimates of the areas of *Land Converted to Grassland* during the inventory time period, stratified by climate region and soil type. If land-use and management data are limited, aggregate data, such as FAO statistics, can be used as a starting point, along with country expert knowledge of the approximate distribution of land-use types being converted and the management of those lands. If the previous land uses and conversions are unknown, SOC stocks changes can still be estimated using the methods provided in *Grassland Remaining Grassland*, but the land base area will likely be different for grasslands in the current year relative to the initial year in the inventory. It is critical, however, that the total land area accounted across all land-use sectors be equal over the inventory time period (e.g., if 3 Million ha of Forest Land and Cropland are converted to Grassland during the inventory time period, then Grassland will have an additional 3 Million ha in the last year of the inventory, while Cropland and Forest Land will have a corresponding loss of 3 Million ha in the last year). *Land Converted to Grassland* is stratified according to climate regions, management, and major soil types, which could either be based on default or country-specific classifications. This can be accomplished with overlays of suitable climate and soil maps, coupled with spatially-explicit data on the location of land conversions.

6.3.3.1 CHOICE OF METHOD

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

Mineral soils

Tier 1

Using Equation 2.25 (Chapter 2), the change in soil organic C stocks can be estimated for mineral soils accounting for the impact of land-use conversion to Grassland. The method is fundamentally the same as the one used for *Grassland Remaining Grassland*, except pre-conversion C stocks are dependent on stock change factors for another land use. Specifically, the initial (pre-conversion) soil organic C stock ($SOC_{(0-T)}$) and stock in the last year of inventory time period (SOC_0) are computed from the default reference soil organic C stocks (SOC_{REF}) stock change factors (F_{LU}, F_{MG}, F_I). Note that area of exposed bedrock in Forest Land or the previous land use are not included in the soil C stock calculation (assume a stock of 0). Annual rates of stock changes are estimated based on the difference in stocks (over time) for the first and last year in the inventory time period divided by the time dependence of the stock change factors (D, 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 more disaggregated land-use activity and environmental data.

Tier 3

Tier 3 methods will involve more detailed and country-specific models and/or measurement-based approaches along with highly disaggregated land-use and management data. It is *good practice* that Tier 3 approaches, estimating soil C change from land-use conversions to Grassland, employ models, data sets and/or monitoring networks that are capable of representing transitions over time from other land uses, including Forest Land, Cropland, and possibly Settlements or other lands. If possible, it is also recommended for Tier 3 methods to be integrated with estimates of biomass removal and the post-clearance treatment of plant residues (including woody debris and litter), as variation in the removal and treatment of residues (e.g., burning, site preparation) will affect C inputs to soil organic matter formation and C losses through decomposition and combustion. It is 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 grassland management on post-conversion change in soil C stocks.

Organic soils

Tier 1 and Tier 2

Land Converted to Grassland on organic soils within the inventory time period is treated the same as *Grassland Remaining Grassland* on organic soils, i.e., they have a constant emission factor applied to them, based on climate regime, and C losses are computed using Equation 2.26 (Chapter 2). Additional guidance on the Tier 1 and 2 approaches are given in the *Grassland Remaining Grassland* section (Section 6.2.3.1).

Tier 3

Similar to mineral soils, a Tier 3 approach will involve more detailed and country-specific models and/or measurement-based approaches along with highly disaggregated land-use and management data (*see Mineral Soils* above for additional discussion).

6.3.3.2 CHOICE OF STOCK CHANGE AND EMISSION FACTORS

Mineral soils

Tier 1

For unmanaged land, as well as for managed Forest Land, Settlements and nominally managed Grassland 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 other systems such as improved and degraded grasslands, as well as all cropland systems. Default reference C stocks are given in Chapter 2, Table 2.3. See the *Choice of Stock Change and Emission Factors* in the appropriate land-use chapter for default stock change factors (Forest Land in Section 4.2.3.2, Cropland in 5.2.3.2, Grassland in 6.2.3.2, Settlements in 8.2.3.2, and Other land in 9.3.3.2).

Note that it is *good practice* to use the management factor (F_{LU}) for set-asides (Table 5.5) if dealing with cultivated annual Cropland converted into Grassland (i.e., until the land is re-classified as *Grassland Remaining Grassland*) because recently converted annual cropland systems will typically gain C at a rate similar to set-aside lands. Moreover, the Tier 1 set-aside factors were derived from empirical data to explicitly represent the expected gain during the first 20 years for lands removed from cultivation. If countries decide to assume a faster increase in C that raises levels to native conditions within 20 years, a justification should be provided in the documentation.

Tier 2
Estimation of country-specific stock change factors is probably the most important development for the Tier 2 approach. Differences in soil organic C stocks among land uses are computed relative to a reference condition, using land-use factor (F_{LU}). Input factor (F_I) and management factor (F_{MG}) are then used to further refine the C stocks of the new grassland system. Additional guidance on how to derive these stock change factors is given in *Grassland Remaining Grassland*, Section 6.2.3.2 as well as other general guidance in Section 2.3.3.1 (Chapter 2). See the appropriate section for specific information regarding the derivation of stock change factors for other land-use sectors (Forest Land in Section 4.2.3.2, Cropland in 5.2.3.2, Settlements in 8.2.3.2, and Other land in 9.3.3.2).

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

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

Organic soils

Tier 1 and Tier 2
Land Converted to Grassland on organic soils within the inventory time period is treated the same as *Grassland Remaining Grassland* on organic soils. Tier 1 emission factors are given in Table 6.3, while Tier 2 emission factors are derived from country-specific or region-specific data.

Tier 3
Constant emission rate factors *per se* are less likely to be estimated in favor of variable rates that more accurately capture land-use and management effects. See Section 2.3.3 in Chapter 2 for further discussion.

6.3.3.3 CHOICE OF ACTIVITY DATA

Mineral soils

Tier 1 and Tier 2
For purposes of estimating soil carbon stock change, area estimates of *Land Converted to Grassland* 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. A detailed description of the default climate and soil classification schemes is provided in Chapter 3. See corresponding sections dealing with each land-use category for sector-specific information regarding the representation 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).

An important issue in evaluating the impact of *Land Converted to Grassland* 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 categorized as *Land Converted to Grassland*. In contrast, aggregate data (Approach 1) only provide the total amount of area in each land use at the beginning and end of the inventory period (e.g., 1985 and 2005). Thus, unless supplementary information can be gathered to infer the pattern of land-use change (as suggested in Chapter 3) Approach 1 data are insufficient to determine specific transitions between land-use categories. Therefore, the previous land use before conversion to grasslands will be unknown. Fortunately, this is not problematic using a Tier 1 or 2 method because the calculation is not dynamic and assumes a step change from one equilibrium state to another. Therefore, with aggregated data (Approach 1), changes in soil organic C stocks may be computed separately for each land-use category and then combined to obtain the total stock change for all land uses combined. The soil C stock change estimate will be equivalent to results using Approach 2 (or 3) activity data (i.e., a full land-use change matrix), but evaluation of C stock trends will only be relevant after combining the stock estimates for all land uses (i.e., stocks will increase or decrease with the changes in land area within individual land uses, but this will offset by gains or losses in other land uses, and thus not an actual stock change in the soil pool for a country. Thus, with aggregate (Approach 1 data) it is important to achieve coordination among all land sector to ensure 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.

Note that it will not be possible to determine the amount of cultivated annual croplands converted to grasslands with aggregated activity data (Approach 1). Therefore, grassland stock change factors will be applied, without consideration for the slower rate of C gain in recently converted annual croplands, which may lead to an over-estimation of C gain over a 20-year time period, particularly using the Tier 1 method (see Choice of Stock

Change and Emission Factors for additional discussion). This caveat should be acknowledged in the reporting documentation, and it is *good practice* for future inventories to gather additional information needed to estimate the area of grassland recently converted from croplands, particularly if soil C is a key source category.

Tier 3

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

Organic soils

Tier 1 and Tier 2

Land Converted to Grassland on organic soils within the inventory time period is treated the same as *Grassland Remaining Grassland* on organic soils, and guidance on activity data is discussed in Section 6.2.3.3.

Tier 3

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

6.3.3.4 CALCULATION STEPS FOR TIER 1

Mineral soils

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

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

Step 2: Determine the land-use and management by mineral soil types and climate regions for land at the beginning of the inventory period, which can vary depending on the time step of the activity data (0-T; e.g., 5, 10 or 20 years ago).

Step 3: Select the native reference C stock value (SOC_{REF}), based on climate and soil type from Table 2.3, for each area of land being inventoried. The reference C stocks are the same for all land-use categories to ensure that erroneous changes in the C stocks are not computed due to differences in reference stock values among sectors.

Step 4: Select the land-use factor (F_{LU}), management factor (F_{MG}) and C input levels (F_I) representing the land-use and management system present before conversion to grassland. Values for F_{LU}, F_{MG} and F_I are given in the respective section for the land-use sector (Cropland in Chapter 5, Grassland in Chapter 6, Settlements in Chapter 8, and Other land in Chapter 9).

Step 5: Multiply these values by the reference soil C stock to estimate 'initial' soil organic C stock ($SOC_{(0-T)}$) for the inventory time period.

Step 6: Estimate SOC_0 by repeating Steps 1 to 4 using the same native reference C stock (SOC_{REF}), but with land-use, management and input factors that represent conditions (after conversion to grassland) in the last (year 0) inventory year.

Step 7: Estimate the average annual change in soil organic C stock for the area over the inventory time period ($\Delta C_{Mineral}$)

Step 8: Repeat Steps 1 to 6 if there are additional inventory time periods (e.g., 1995 to 2000, 2001 to 2005, etc.).

A numerical example is given below for land conversion of cropland.

Using Equation 2.25 (Chapter 2), default stock change factors and reference C stocks, a case example is given below for estimating changes in soil organic C stocks associated with *Land Converted to Grassland*.

Example: For tropical moist, volcanic soil that has been under long-term annual Cropland, with intensive tillage and where crop residues are removed from the field, carbon stocks at the beginning of the inventory time period (1990 in this example), $SOC_{(0-T)}$ are 70 tonnes C ha^{-1} ● 0.48 ● 1 ● 0.92 = 30.9 tonnes C ha^{-1}. Following conversion to improved (e.g., fertilised) pasture, carbon stocks in the last year of inventory (2010 in this example) (SOC_0) are 70 tonnes C ha^{-1} ● 0.82 ● 1.17 ● 1 = 67.2 tonnes C ha^{-1}. Thus the average annual change in soil C stock for the area over the inventory time period is calculated as (67.2 tonnes C ha^{-1} – 36.9 tonnes C ha^{-1}) / 20 yrs =1.5 tonnes C ha^{-1} yr^{-1}. Note that the set-aside factor (0.82) from croplands was used for the F_{LU} because grasslands do not gain the full complement of the native C stock in 20 years. After the first 20 years, a factor of 1 would be used for F_{LU} in the Tier 1 approach.

Organic soils

Calculation steps are the same as described in Section 6.2.3.4 above.

6.3.3.5 UNCERTAINTY ASSESSMENT

Uncertainty analyses for *Land Converted to Grassland* are fundamentally the same as *Grassland Remaining Grassland*. Three broad sources of uncertainty exists: 1) uncertainties in land-use and management activity and environmental data; 2) uncertainties in reference soil C stocks if using a Tier 1 or 2 approach (mineral soils only); and 3) uncertainties in the stock change/emission factors for Tier 1 or 2 approaches, model structure/parameter error for Tier 3 model-based approaches, or measurement error/sampling variability associated with a Tier 3 measurement-based inventories. See the uncertainty section in *Grassland Remaining Grassland* for additional discussion (Section 6.2.3.5).

6.3.4 Non-CO_2 greenhouse gas emissions from biomass burning

Greenhouse gas emissions from *Land Converted to Grassland* occur from combustion of biomass and dead organic matter (DOM) in *Land Converted to Grassland*. Emissions are accounted for in the new land category. The most significant greenhouse gas emissions in this section arise from conversion of Forest Land to Grassland, but important emissions may also occur as a result of the conversion of Cropland to Grassland. It is very unlikely that Grassland originates from conversion of the other land-use categories (Settlements, Wetlands, or Other land).

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

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

The conversion of Cropland to Grassland does not normally result in biomass burning. However, whenever it is practiced, countries should report the corresponding greenhouse gas emissions, on an annual basis.

The approach to be used to estimate non-CO_2emissions from biomass burning in *Land Converted to Grassland* is essentially the same as that presented for *Grassland Remaining Grassland*.

6.3.4.1 CHOICE OF METHOD

The decision tree in Figure 2.6 in Chapter 2 provides guidance on the choice of the Tier level to be applied by countries when reporting greenhouse gas emissions from *Land Converted to Grassland*.

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

Countries should report using a Tier 2 or Tier 3 method whenever greenhouse gas emissions from biomass burning in *Land Converted to Grassland* is a key category.

6.3.4.2 CHOICE OF EMISSION FACTORS

Tier 1
The mass of fuel available for combustion (quantity M_B in Equation 2.27) is critical for estimating greenhouse gas emissions. Default data to support estimation of emissions under a Tier 1 approach are provided in Tables 2.4 to 2.6 in Chapter 2. Countries need to judge how their different vegetation types map onto the broad vegetation categories described in the default tables. For Tier 1, it should be assumed that all above-ground biomass and DOM in the previous land-use category is lost immediately after conversion. Default values for biomass prior to conversion can be found in the chapters relating to the respective land uses (e.g., default factors for Forest Land are to be found in the chapter dealing with biomass in Forest Land).

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

Tier 3
Under a Tier 3, all the parameters should be country defined.

6.3.4.3 CHOICE OF ACTIVITY DATA

The activity data needed to estimate greenhouse gas emissions from biomass burning refers to the area affected by this activity. Countries shall stratify the area converted to Grassland by Forest Land- and by Cropland-converted, since the amount of fuel available for burning may vary markedly from one category of land use to another.

Tier 1
Countries applying a Tier 1 approach should estimate the areas converted to Grassland from initial land uses (Forest Land, Cropland, etc.). The conversion should be estimated on a yearly basis. The estimates can be derived from several approaches: (1) applying a rate of conversion to Grassland to the total annual area converted (the rate can be estimated on the basis of historical knowledge, judgement of country experts, and/or from samples of converted areas and assessment of the final land use); or (2) using data from international sources, such as FAO, to estimate the area of Forest Land and Cropland annually converted, and using expert judgement to estimate the portion of this area converted to Grassland.

Tier 2
Countries should, wherever possible, use actual area estimates for all possible conversions to grassland. Multi-temporal remotely sensed data of adequate resolution should provide better estimates of land-use conversion than the approaches introduced in Tier 1. The analysis may be based on full coverage of the territory or on representative samples selected, from where estimates of the area converted to grassland in the entire territory can be derived.

Tier 3
The activity data in Tier 3 should be based on the Approach 3 method presented in Chapter 3, where the total annual area converted to Grassland (from Forest Land, Cropland, or other land-use categories) is estimated. The data should be disaggregated according to the type of biome, climate, political boundaries, or a combination of these parameters.

6.3.4.4 UNCERTAINTY ASSESSMENT

Tier 1
The sources of uncertainty in this method arises from many sources: (i) use of global or national average rates of conversion and coarse estimates of land areas converted to grassland; (ii) estimate of the area converted that is burnt as part of a management practice (disposal of the biomass in the initial land use to establish the agriculture land); (iii) mass of available fuel; and (iv) combustion and emission factors. Uncertainties associated with emission and combustion factors are provided, and those related to items (i) and (ii) can vary significantly

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

Tier 2

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

Tier 3

The uncertainty associated with activity data in Tier 3 is likely to be smaller than that in Tier 1 or 2, and is dependent on the remote sensing and field surveys, modelling approach used, and the data inputs.

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

6.4.1 Completeness

Tier 1

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

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

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

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

For biomass burning, non-CO_2 greenhouse gases should be reported for all controlled burns and wildfires on managed grasslands. This includes conversion of Forest Land to Grassland, where the amount of fuel available for burning is usually more significant than in the other land-use categories; emissions from burning of DOM and cleared tree biomass should be included in these estimates. Savannah burning also constitutes a large source of non-CO_2 emissions from biomass burning. Biomass burning should be reported where wildfire on unmanaged land is followed by transition to managed land during the inventory reporting period.

Estimation of the area actually burnt is critical to the reliable calculation of non-CO_2 greenhouse gas emissions. Remotely-sensed estimates of the area burnt need to be rigorously tested against ground data to ensure that areas burnt are accurately estimated. The use of regionally average statistics is likely to be highly unreliable for estimating the area burnt in a specific country.

In grasslands where fire management is changing the balance between grass and woody vegetation, the emissions of CO_2 in fire may not be balanced by the re-fixation of an equivalent amount of C into biomass in the short-term. In such situations, net release of CO_2 caused by burning should also be reported.

Tier 2

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

Tier 3

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

6.4.2 Developing a consistent times series

Tier 1

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

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

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

For C stock changes, one key element in producing a consistent time series is to ensure consistency between carbon stocks for *Land Converted to Grassland* that were estimated in previous reporting periods and the state of those stocks reported for those lands that are remaining grasslands in the current reporting period. For example, if 10 tonnes of the above-ground live biomass was transferred to the dead organic matter pool from *Forest Land Converted to Grassland* in the previous reporting period, reporting in the current period must assume that the starting C stocks in the dead organic matter pool was 10 tonnes for those lands.

Tier 2

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

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

Tier 3

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

6.4.3 Quality Assurance and Quality Control

Tier 1

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

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

External reviews need to consider the validity of the inventory approach, thoroughness of inventory documentation, methods explanation and overall transparency. It is important to evaluate if the total area of managed grassland is realistic, taking into account the total grassland area of the territory. Cross-checking area estimates across land-use categories (i.e., Forest Land, Cropland, Grassland, etc.) will also be necessary. Ultimately, the sum of the entire land base for a country, which includes each sector, must be equal across every year in the inventory time period.

For biomass burning, specific attention should be given to country-specific estimates of annual area burnt. When estimating area burnt from global datasets, it is important to validate the information using field data or high resolution remotely-sensed data.

Tier 2

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

Given the complexity of emission and removal trends, specialists in the field should be involved in the external review to check country-specific factors and/or classifications.

Tier 3

Country-specific inventory systems will likely need additional Quality Assurance/Quality Control measures beyond those listed for Tiers 1 and 2, but this will depend on the systems that are developed. It is *good practice* to develop a Quality Assurance/Quality Control protocol that is specific to the country's advanced inventory system, archive the reports, and include summary results in reporting documentation.

6.4.4 Reporting and Documentation

Tier 1

In general, it is *good practice* to document and archive all information required to produce national inventory estimates. For Tier 1, inventory compilers should document activity data trends and uncertainties in grasslands. Key activities include land-use change, biomass burning, use of silvopastoral practices, grazing intensity, use of mineral fertilizers or organic amendments, irrigation practices, liming, inter-seeding with legumes or planting more productive species, and biomass burning (wildfires and controlled burns).

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

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

It is *good practice* to document and explain trends in biomass and soil C stocks, as well as biomass burning emissions in terms of the land-use and management activity. Changes in biomass stocks should be linked directly to land use, to changes in silvipastoral practices or woody plant encroachment; while trends in soil C stocks may be due to land use or shifts in key management activities as described above. Biomass burning emissions will depend on the extent and frequency of controlled burns and wildfires. Significant fluctuations in emissions between years should be explained.

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

Tier 2

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

Reporting documentation should include the new factors (i.e., means and uncertainties), and it is *good practice* to include a discussion in the inventory report about differences between country-specific factors and Tier 1 defaults as well as Tier 2 factors from regions with similar circumstances as the reporting country. If different emission factors, parameters and methods are used for different years, the reasons for these changes should be explained and documented. In addition, inventory agencies should describe country-specific classifications for management, climate and/or soil types, and it is recommended that improvements to the inventory estimates based on the new classifications be documented. For example, grassland condition may be subdivided into additional categories beyond the Tier 1 classes (i.e., nominal, improved, degraded and severely degraded), but further subdivisions will only improve inventory estimates if the stock change or emission factors differ significantly among the new categories.

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

Tier 3

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

Annex 6A.1 Estimation of default stock change factors for mineral soil C emissions/removals for Grassland

Default soil C stock change factors are provided in Table 6.2 that were computed from a global dataset of experimental studies for three general types of grassland condition: degraded, nominally managed, and improved grassland. An additional input factor was included for application to improved grassland. The management improvements considered here were limited to fertilization (organic or inorganic), sowing legumes or more grass species, and irrigation. Overgrazed grassland and poorly managed (i.e., none of the management improvements were applied) tropical pastures were classified as degraded grassland. Native or introduced grasslands that were unimproved were grouped into the nominal grassland classification. Grasslands with any single type of management improvement were classified as improved grassland with medium C input rates. For improved grassland in which multiple management improvements were implemented, C input rates were considered high.

Experimental data (citations provided in reference list) were analyzed in linear mixed-effects models, accounting for both fixed and random effects. Fixed effects included depth, number of years since the management change, and the type of management change (e.g., reduced tillage vs. no-till). For depth, we did not aggregate data but included C stocks measured for each depth increment (e.g., 0-5 cm, 5-10 cm, and 10-30 cm) as a separate point in the dataset. Similarly, we did not aggregate data collected at different points in time from the same study. Consequently, random effects were used to account for the dependence in times series data and among data points representing different depths from the same study. If significant, a country-level random effect was used to assess an additional uncertainty associated with applying a global default value to a specific country (included in default uncertainty). Factors were estimated for the effect of the management practice at 20 years for the top 30 cm of the soil. Variance was calculated for each of the factor values, and can be used with simple error propagation methods to construct probability distribution functions with a normal density.

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