MODULE 5
LAND-USE CHANGE & FORESTRY

5. LAND-USE CHANGE & FORESTRY

5.1 Introduction

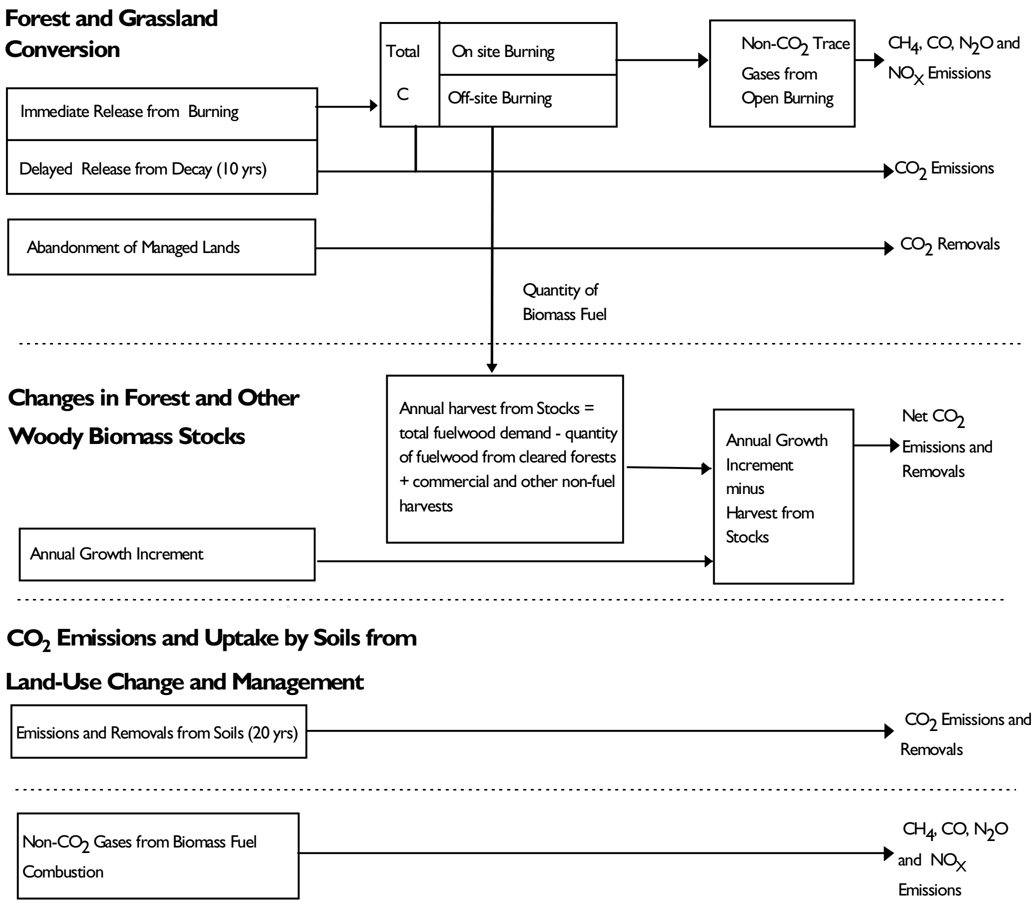
The priority calculations of emissions from land-use change and forestry focus upon three activities which are sources or sinks of carbon dioxide. It must be pointed out that there are inherently large uncertainties or errors associated with these calculations. Future work will develop guidance for estimating and expressing these errors. One of these activity types is also a source of non-CO_2 trace gas (CH_4, CO, N_2O, and NO_x) emissions, and these are also calculated here. NMVOCs are not treated here, although it is recognised that forests are a potential anthropogenic source of these gases.

On a global scale the most important land-use changes and management practices that result in CO_2 emissions and uptake are:

- changes in forest and other woody biomass stocks
- forest and grassland conversion
- abandonment of managed lands

The immediate release of non-CO_2 trace gases from the burning associated with forest/grassland conversion is also calculated. These calculations are very similar to calculations of non-CO_2 trace gas emissions from burning of savannas and agricultural residues (in the Agriculture module, Chapter 4). Calculations of non-CO_2emissions from biomass fuel combustion is done in the Energy Module. The present module deals with the sources and sinks of greenhouse gases from biomass and soil.

FIGURE 5-1 : RELATIONSHIPS AMONG CATEGORIES



The diagram above illustrates the relationships between the categories in this module and also with biomass fuel combustion in the Energy module. The key linkages are:

1 To estimate CO_2 emissions from burning during forest/grassland conversion it is only necessary to know the total amount of biomass burned as a result of that land conversion in the particular year of the inventory.

2 Total biomass burned must be divided into *on-site* and *off-site* (i.e., fuelwood) because the type of burning affects the emissions of non-CO_2 trace gases such as methane, and therefore different emissions factors may be applied to open burning (on-site) and to fuelwood use (off-site).

3 Countries which have good statistics on direct harvesting of all types of woody biomass and all uses of biomass for fuel should use these data. In many countries, significant amounts of wood removed from forests and other biomass stocks (primarily for domestic use) are not included in commercial harvest statistics. These countries can use statistics of fuelwood consumption published by the FAO. These statistics are based on household and other fuel consumption surveys, scaled to population, in order to estimate annual demand for fuelwood and other traditional fuels. This information can be used **instead of or in combination with** commercial harvest and sales statistics.

Fuelwood consumption information is used in two ways:

- for estimating non-CO_2 trace gas emissions from biomass fuel combustion.
- total wood consumption, corrected to deduct any wood which has come from forest and grassland conversion (CO_2 already accounted for) is also a key input for calculating net CO_2 emissions or removals due to changes in forest and other woody biomass stocks.

5.2 Changes in Forest and Other Woody Biomass Stocks

5.2.1 Introduction

This submodule deals with the emissions or removals of carbon (and carbon dioxide) due to changes in forest and other woody biomass stocks affected by human activity.

5.2.2 Data Sources

FAO Yearbooks of Forest Products (annual)

There are also a number of international data bases with country-specific statistics, as well as studies of individual countries. These include:

Forest Resources Assessment 1990: Tropical Countries (FAO, 1993).

The Forest Resources of the Temperate Zones (ECE/FAO, Geneva, 1992).

For a fuller bibliography, see *The IPCC Greenhouse Gas Inventory Reference Manual.*

CATEGORIES OF WOODY BIOMASS

Village, farm or urban trees and other afforestation programmes are included to allow users to account for biomass in trees outside normal forests. These may be important for fuelwood accounting in some countries. Users must provide all data for these categories.

5.2.3 Methodology

To calculate the net uptake of CO_2, the annual increment of biomass in plantations, forests which are logged or otherwise harvested, the growth of trees in villages, farms and urban areas and any other significant stocks of woody biomass, is estimated.

Wood harvested for fuelwood, commercial timber and other uses is also estimated as significant quantities may be gathered informally for traditional fuelwood consumption. In this case the commercial statistics should be supplemented by FAO fuelwood consumption data.

The net carbon uptake due to these sources is then calculated. If the figure is positive then this counts as a removal of CO_2, and if the figure is negative, it counts as an emission. Finally, the net carbon uptake/emission is expressed as CO_2.

Completing the Worksheet

USING THE WORKSHEET

- Copy the Worksheet at the end of this section to complete the inventory.
- Keep the original of the Worksheet blank so you can make further copies if necessary.

STEP 1 ESTIMATING TOTAL CARBON CONTENT IN ANNUAL GROWTH OF LOGGED AND PLANTED FORESTS

Use WORKSHEET 5-1 CHANGES IN FOREST AND OTHER WOODY BIOMASS STOCKS at the end of this module to record inventory data.

1 For each type of biomass stock, enter the Area of Forest/Biomass Stocks in kilohectares (kha) in lower column A.

2 For dispersed (non-forest) trees (e.g., urban, village and farm trees), enter the number of trees (in 1000s of trees) in lower column A.

3 For each type of forest, enter the Annual Growth Rate (in tonnes of dry matter per hectare) in column B.

The default statistics in Tables 5-1 or 5-6 can be used if national data are not available. Using defaults would result in highly uncertain national estimates.

TABLE 5-1
AVERAGE ANNUAL ACCUMULATION OF DRY MATTER AS BIOMASS IN PLANTATIONS

Forest Types		Annual Increment in Biomass (tonnes dm/ha/year)
Tropical	*Acacia spp.*	15.0
	Eucalyptus spp.	14.5
	Tectona grandis	8.0
	Pinus spp	11.5
	Pinus caribaea	10.0
	Mixed Hardwoods	6.8
	Mixed Fast-Growing Hardwoods	12.5
	Mixed Softwoods	14.5
Temperate	Douglas fir	6.0
	Loblolly pine	4.0

Note: These are average accumulation rates over expected plantation lifetimes; actual rates will depend upon the age of the plantation.

The data for the temperate species are based upon measurements in the United States. Data on other species and from other regions should be supplied by individual countries (as available).

Additional temperate estimates by species and country can be derived from data in ECE/FAO (1992), assuming that country averages of net annual increment for managed and unmanaged lands are reasonable approximations for plantations.

4 For other non-forest trees, enter the Annual Growth Rate in kilotonnes of dry matter per thousand trees in column B, i.e., take average growth rate per tree and multiply by 1,000.

5 For each type of forest/grassland, multiply the Area of Forest/Biomass Stocks by the Annual Growth Rate to give the Annual Biomass Increment in kilotonnes of dry matter. Enter the result in column C.

6 For non-forest trees, multiply the Number of Trees by the Annual Growth Rate to give the Annual Biomass Increment in kilotonnes of dry matter. Enter the result in column C.

7 For each type of biomass stock, enter the Carbon Fraction of Dry Matter.

The default value is 0.5 for all biomass, if specific values are not available.

8 Multiply the Annual Biomass Increment by the Carbon Fraction of Dry Matter to give the Total Carbon Uptake Increment. Enter the result in column E.

9 Add the figures in column E and enter the total in the Total box at the bottom of the column.

USING COMMERCIAL HARVEST STATISTICS

Commercial harvest statistics are often provided for the commercial portion of the biomass only, in cubic metres (m^3) of roundwood. In this case the harvested amounts must be adjusted in two ways to reflect the values needed for the emissions/removals calculations. The volume of biomass expressed as m^3 must be converted to mass of dry matter expressed as tonnes (t dm).

- The default conversion ratio is 0.5 t dm/m^3.

In addition, an expansion ratio can be applied to account for the non-commercial biomass (limbs, small trees etc.) harvested with the commercial roundwood and left to decay. The following default ratios can be used:

- Undisturbed forests 1.75
  Logged forests 1.90
  Unproductive forests 2.00

If the forest type from which commercial roundwood has been harvested is known, the appropriate ratio can be applied. The value for logged forests could be used as a general default. More detailed formulae for deriving expansion ratio as a function of pre-harvest biomass density are discussed in the *Reference Manual*.

If both conversion and expansion are needed, they can be combined by using ratios which are the product of the two:

Forest type	*t dm total biomass/ m^3 commercial roundwood*
Undisturbed forests	*0.88*
Logged forests	*0.95*
Unproductive forests	*1.0*

Some harvest statistics are provided on a total biomass basis (expansion ratios already applied) or may be provided in mass of dry matter rather than volume. It is important that users determine carefully the nature of the values in their sources of commercial harvest data, then apply the appropriate conversions or expansions to get total biomass harvested. This can be:

a volume to mass conversion alone

b expansion from commercial to total mass of dry matter

c a combination of both (*a* and *b*)

STEP 2 ESTIMATE THE AMOUNT OF BIOMASS HARVESTED

1 Enter the amount of the Commercial Harvest in thousands of cubic metres in column F.

These values should be taken from local sources. FAO published values can be used as defaults. See the margin box *Using Commercial Harvest Statistics*.

2 Enter the Biomass Conversion/Expansion Ratio in tonnes of dry matter per cubic metre (t dm/m^3) in column G if necessary.

3 Multiply the Commercial Harvest by the Biomass Conversion/Expansion Ratio (if necessary) to give the Total Biomass Removed in Commercial Harvest in kilotonnes of dry matter. Enter the result in column H.

4 Enter Total Fuelwood Consumed (including wood for charcoal production) from FAO fuelwood consumption statistics.

5 Enter the quantity of Total Other Wood Use in kilotonnes dm in column J.

If any wood is removed but is not accounted for in harvest statistics for commercial harvest or fuelwood consumption it can be entered here.

6 Add the Total Fuelwood Consumed (column I) to the Total Biomass Removed in Commercial Harvest (column H) and Total Other Wood Use (column J) to give Total Biomass Consumption. Enter the result in column K. Sum this column and enter the result in the Totals box at the foot of the column.

7 Enter Wood Removed From Forest Clearing (total figure from column M, Worksheet 5-2, sheet 3, Quantity of Biomass Burned Off Site) at the bottom of column L.

8 Subtract Wood Removed From Forest Clearing from Total Biomass Consumption to give Total Biomass Consumption From Stocks in kilotonnes of dry matter. Enter the result in the box at the bottom of column M.

STEP 3 CONVERT WOOD HARVESTED TO CARBON REMOVED

1 Enter the Carbon Fraction in column N (the general default value for live biomass is 0.5).

2 Multiply Total Biomass Consumption From Stocks (column M) by Carbon Fraction (column N) to give Annual Carbon Release (in kilotonnes of carbon). Enter the result in column O.

STEP 4 ESTIMATE THE NET ANNUAL AMOUNT OF CARBON UPTAKE OR RELEASE

1. Subtract Annual Carbon Release (column O) from Total Carbon Increment (column E) to give Net Annual Carbon Uptake or Release. Enter the result in column P.
2. Multiply the Net Annual Carbon Uptake or Release (column P) by 44/12 to give the Annual CO_2 Removal (if a positive value) or Emission (if a negative value). Enter the result in column Q.
3. For summary reporting purposes and for consistency with other emission/removal categories, it is necessary to reverse the sign of these results, to express emissions as a positive value and removals as negative.

5.3 CO_2 Emissions from Forest and Grassland Conversion

5.3.1 Introduction

Forest and grassland conversion to permanent cropland or pasture is primarily an activity of the tropics. Tropical forest clearing is usually accomplished by cutting undergrowth and felling trees followed by burning biomass on-site or as fuelwood. By this process some of the biomass is burned while some remains on the ground where it decays slowly (usually over a period of ten years in the tropics). Of the burned material, a small fraction (5-10 per cent) is converted to charcoal which resists decay for 100 years or more, and the remainder is released instantaneously into the atmosphere as CO_2.

Where conversion of forest and grassland to permanent cropland and pasture occurs outside the tropics, the basic calculations should still be the same.

Carbon is also lost from the soils after conversion, particularly when the land is cultivated. Conversion of grasslands into cultivated lands also results in CO_2 emissions, mainly from soils. Estimates of carbon emissions from these practices in Section 5.6.

5.3.2 Data Sources

To carry out the inventory task in this section you need the following forest/grassland area statistics.

Forest/grassland areas converted to cropland and pasture, by type over two time periods:

- the inventory year
- the past ten years

Satellite images, aerial photography and land-based surveys are all possible sources of data.

There are also a number of international data bases with country-specific statistics, as well as studies of individual countries. These include:

Forest Resources Assessment 1990: Tropical Countries (FAO, 1993). Summary tables for tropical countries are included in the *Workbook*.

The Forest Resources of the Temperate Zones, (ECE/FAO, Geneva, 1992).

For a fuller bibliography, see *Reference Manual*.

5.3.3 Methodology

Three sets of calculations are used to produce estimates of CO_2 emissions due to forest/grassland conversion:

- Carbon dioxide emitted by burning aboveground biomass (*immediate* emissions, occurring in the year of conversion)
- Carbon dioxide released by decay of aboveground biomass (*delayed* emissions, occurring over a ten-year period)
- Carbon dioxide released from soil (calculated in Section 5.6).

The totals are added together to arrive at total for carbon released from vegetation. Total carbon released is then converted to CO_2 emissions.

Completing the Worksheet

USING THE WORKSHEET

- Copy the Worksheet at the end of this section to complete the inventory.
- Keep the original of the Worksheet blank so you can make further copies if necessary.

STEP 1 ESTIMATING BIOMASS CLEARED

Use WORKSHEET 5-2 FOREST AND GRASSLAND CONVERSION, at the end of this module to record inventory data. You should do this for each forest/grassland type:

1 Enter the figures for Area Converted Annually in kilohectares in column A. Default values for tropical forests from FAO, reported by the forest categories in Box 2 and Table 5-1 of the *Reference Manual* are shown in Table 5-4.

See also Technical Appendix, Chapter 5 of the *Reference Manual* for a discussion of other international sources of data.

2 Enter the figures for Biomass Before Conversion in tonnes of dry matter per hectare (t dm/ha) in column B. Default values are shown in Tables 5-5 and 5-6.

3 Enter the figures Biomass After Conversion in tonnes of dry matter per hectare (t dm/ha) in column C.

This figure includes any biomass not fully cleared (default value = 0) plus regrowth in agricultural use. The default value is 10 tonnes dry matter per hectare if annual crops; and can be significantly higher if woody perennials (e.g., coffee, rubber trees) are planted (see *Reference Manual)*.

TABLE 5-4 FOREST AREA (1000 HA) AND RATES OF CONVERSION (RC, 1000 HA/YR) FOR TROPICAL COUNTRIES									
Africa									
Countries	Wet			Moist With Short Dry Season			Moist With Long Dry Season		
	1980	1990	RC	1980	1990	RC	1980	1990	RC
Angola				3123.3	2904.5	21.9	9717.9	9037.3	68.1
Botswana									
Burundi							50.6	47.0	0.4
Cameroon	8386.0	8020.5	36.5	8573.2	8098.1	47.5	1987.5	1793.6	19.4
Cape Verde									
Central African Rep.	706.3	706.3		11095.2	10504.7	59.0	18400.9	17761.8	63.9
Chad							4414.0	3932.2	48.2
Congo	7794.8	7667.1	12.8	12393.0	12197.9	19.5			
Benin				847.1	838.4	0.9	3903.1	3344.5	55.9
Equatorial Guinea	915.7	882.2	3.3	965.4	929.6	3.6			
Ethiopia									
Djibouti									
Gabon	1228.2	1154.5	7.4	18170.0	17080.0	109.0			
Gambia							85.5	79.1	0.6
Ghana				3910.9	3575.9	33.5	6581.0	5575.5	100.5
Guinea	388.3	384.7	0.4	1204.3	1119.8	8.5	5820.0	5060.2	76.0
Ivory Coast				8537.0	7519.2	101.8	3482.8	3312.1	17.1
Kenya				12.9	12.9				
Liberia	948.0	892.5	5.5	3939.1	3740.8	19.8			
Madagascar	4780.9	4506.7	27.4				4190.9	3777.1	41.4
Malawi							3397.9	2947.7	45.0
Mali							4082.8	3705.6	37.7
Mauritania									
Mozambique				965.9	903.0	6.3	6180.5	5623.0	55.7
Namibia									
Niger									
Nigeria	1269.1	1196.6	7.2	6371.4	5983.5	38.8	6649.1	6027.5	62.2
Guinea-Bissau				129.4	129.4		2050.9	1892.0	15.9
Zimbabwe									
Rwanda									
Senegal							2766.9	2585.9	18.1
Sierra Leone	805.2	756.1	4.9	883.3	829.4	5.4	296.5	278.4	1.8
Somalia									
Sudan				2149.3	1797.5	35.2	12456.1	10674.9	178.1
Tanzania				667.7	626.0	4.2	15738.5	13502.2	223.6
Togo				320.5	293.1	2.7	1214.0	1025.2	18.9
Uganda							1229.0	1090.8	13.8
Burkina Faso							2265.1	2112.5	15.3
Zaire	64047.7	60436.6	361.1	42769.1	40380.1	238.9	5446.7	4829.0	61.8
Zambia							24221.2	21676.1	254.5
TOTAL	91270.0	86603.9	466.6	127027.8	119463.4	756.4	146629.2	131691.0	1493.8

TABLE 5-4 (CONT.)
FOREST AREA (1000 HA) AND RATES OF CONVERSION (RC, 1000 HA/YR) FOR TROPICAL COUNTRIES

Africa

Countries	Dry			Montane Moist			Montane Dry		
	1980	1990	RC	1980	1990	RC	1980	1990	RC
Angola	7761.8	7218.1	54.4	3401.3	3163.1	23.8			
Botswana	3098.9	2940.4	15.8						
Burundi				59.8	56.8	0.3	136.2	128.8	0.7
Cameroon	637.8	584.5	5.3	1897.7	1767.4	13.0			
Cape Verde									
Central African Rep.	845.8	816.8	2.9	806.3	772.2	3.4			
Chad	5285.5	5024.3	26.1						
Congo									
Benin	894.1	764.4	13.0						
Equatorial Guinea				14.9	14.3	0.1			
Ethiopia	2065.8	2007.6	5.8	5524.2	5347.9	17.6	838.3	824.9	1.3
Djibouti									
Gabon									
Gambia	19.0	17.5	0.1						
Ghana	438.2	403.8	3.4						
Guinea				145.4	127.6	1.8			
Ivory Coast				77.6	72.7	0.5			
Kenya	18.8	18.8		725.4	678.0	4.7	240.0	230.2	1.0
Liberia				0.2	0.2	0.0			
Madagascar	2424.5	2219.3	20.5	4985.4	4596.2	38.9			
Malawi	191.0	165.6	2.5	422.1	372.7	4.9			
Mali	4954.6	4547.6	40.7						
Mauritania									
Mozambique	10881.1	10162.9	71.8	14.0	13.1	0.1			
Namibia	2607.3	2520.9	8.6						
Niger	190.4	190.4							
Nigeria	1444.6	1380.1	6.4	267.4	243.2	2.4			
Guinea-Bissau									
Zimbabwe	8258.8	7729.4	52.9	73.3	68.6	0.5			
Rwanda				137.5	134.0	0.3	30.7	29.9	0.1
Senegal	1845.8	1716.3	12.9						
Sierra Leone				26.3	24.7	0.2			
Somalia									
Sudan	19514.6	17757.2	175.7	600.3	502.3	9.8	235.9	217.3	1.9
Tanzania	13677.7	12374.6	130.3	3054.7	2705.2	34.9	367.8	329.5	3.8
Togo	36.9	34.5	0.2						
Uganda				4701.0	4281.5	42.0	763.1	698.2	6.5
Burkina Faso	1643.8	1533.1	11.1						
Zaire	118.2	111.0	0.7	8138.5	7448.3	69.0	76.4	69.8	0.7
Zambia	11347.8	10287.7	106.0	361.6	337.5	2.4			
TOTAL	100202.7	92526.9	767.6	35434.9	32727.3	270.8	2688.3	2528.5	16.0

TABLE 5-4 (CONT.)
FOREST AREA (1000 HA) AND RATES OF CONVERSION (RC, 1000 HA/YR) FOR TROPICAL COUNTRIES

Continental and Insular South and South-East Asia

Countries	Wet			Moist With Short Dry Season			Moist With Long Dry Season		
	1980	1990	RC	1980	1990	RC	1980	1990	RC
Bangladesh	895.5	572.2	32.3				249.5	197.3	5.2
Bhutan	186.3	176.0	1.0						
Brunei	476.4	458.3	1.8						
Myanmar	13709.9	12093.8	161.6				12123.8	10426.7	169.7
Sri Lanka	263.2	247.0	1.6				705.8	605.3	10.1
India	8723.4	8228.5	49.5				7422.8	7044.7	37.8
Indonesia	104211.8	93949.9	1026.2	3284.0	3005.3	27.9	457.8	360.8	9.7
Cambodia	1873.0	1689.3	18.4				4002.9	3610.4	39.3
Laos	4356.4	3960.2	39.6				4969.9	4542.4	42.7
Malaysia	20028.0	16338.8	368.9						
Nepal	647.9	608.7	3.9				1382.8	1300.1	8.3
Pakistan							15.4	10.9	0.5
Papua New Guinea	30244.2	29323.5	92.1	727.2	705.0	2.2			
Philippines	6610.2	4214.2	239.6	919.6	593.6	32.6	1442.1	1004.0	43.8
Singapore	4.4	4.4							
Thailand	4589.9	3081.6	150.8				7189.3	5231.7	195.8
Vietnam	3371.6	2894.5	47.7				3939.1	3381.6	55.7
TOTAL	200192.2	177840.6	2235.2	4930.9	4303.9	62.7	43901.3	37715.9	618.5

Countries	Dry			Montane Moist			Montane Dry		
	1980	1990	RC	1980	1990	RC	1980	1990	RC
Bangladesh									
Bhutan				2360.9	2230.4	13.1			
Brunei									
Myanmar	393.4	351.1	4.2	6588.8	5941.8	64.7			
Sri Lanka	988.1	836.1	15.2	57.6	57.3	0.0			
India	28393.5	26252.3	214.1	9159.0	8803.8	35.5	116.4	116.4	
Indonesia	80.0	72.9	0.7	13555.9	12083.2	147.3			
Cambodia	7506.8	6770.7	73.6	94.5	92.7	0.2			
Laos	2473.5	2267.0	20.7	2667.5	2403.5	26.4			
Malaysia				1517.6	1244.3	27.3			
Nepal	39.3	37.1	0.2	2691.2	2361.2	33.0			
Pakistan	5.9	4.2	0.2	824.5	583.3	24.1	1186.4	839.3	34.7
Papua New Guinea	430.4	417.2	1.3	5538.4	5369.8	16.9			
Philippines				2019.4	2019.4				
Singapore									
Thailand	4382.6	3159.1	122.3	1726.1	1262.9	46.3			
Vietnam	1108.5	951.6	15.7	1263.3	1084.5	17.9			
TOTAL	45801.9	41119.2	468.3	50064.4	45538.0	452.6	1302.8	955.7	34.7

TABLE 5-4 (CONT.) FOREST AREA (1000 HA) AND RATES OF CONVERSION (RC, 1000 HA/YR) FOR TROPICAL COUNTRIES									
Central and South America and Caribbean									
Countries	Wet			Moist With Short Dry Season			Moist With Long Dry Season		
	1980	1990	RC	1980	1990	RC	1980	1990	RC
Antigua And Barbuda							10.0	9.8	0.0
Bahamas							153.7	123.8	3.0
Bolivia				23967.7	21453.8	251.4	16024.9	14128.2	189.7
Brazil	301722.3	291596.6	1012.6	95197.0	87729.1	746.8	118943.9	109353.2	959.1
Belize	1798.0	1755.4	4.3				238.4	238.4	
Colombia	49682.6	47455.3	222.7	705.7	549.5	15.6	4347.1	3551.0	79.6
Costa Rica	842.2	625.1	21.7				0.0	0.0	0.0
Cuba	125.3	113.8	1.1				1372.6	1246.8	12.6
Dominica	47.3	44.1	0.3						
Dominican Republic	451.8	340.9	11.1				362.3	273.3	8.9
Ecuador	8572.4	7149.9	142.3	1619.5	1350.8	26.9	381.0	317.8	6.3
El Salvador	40.8	32.6	0.8				15.3	12.2	0.3
French Guyana	7996.2	7993.5	0.3	3.1	3.1				
Grenada							3.6	5.5	-0.2
Guadeloupe	95.5	92.5	0.3						
Guatemala	3820.1	3402.9	41.7				730.5	730.5	
Guyana	11671.1	11671.1		1217.9	1176.1	4.2	4039.8	3901.4	13.8
Haiti	7.4	4.5	0.3				14.3	8.8	0.6
Honduras	1597.5	1285.9	31.2				542.4	436.6	10.6
Jamaica	259.4	122.2	13.7				240.7	113.4	12.7
Martinique	45.0	42.8	0.2						
Mexico	2717.6	2440.8	27.7				13091.1	11110.3	198.1
Nicaragua	4477.8	3712.2	76.6				419.6	347.8	7.2
Panama	2136.6	1801.8	33.5				67.6	66.5	0.1
Paraguay				843.2	473.0	37.0	7681.4	5564.2	211.7
Peru	41501.0	40358.0	114.3	12679.3	12298.8	38.1			
Puerto Rico	42.8	49.4	-0.7				130.7	150.6	-2.0
St. Kitts and Nevis							13.0	13.2	0.0
St. Lucia	7.7	4.5	0.3						
St. Vincent	12.7	10.3	0.2				0.3	0.2	0.0
Surinam	9490.2	9405.3	8.5	1086.7	1044.5	4.2	4317.7	4317.7	
Trinidad and Tobago	191.8	155.0	3.7						
Venezuela	21073.8	19601.8	147.2	3434.7	2978.1	45.7	15403.0	12487.3	291.6
TOTAL	470426.8	451267.9	1915.9	140754.7	129056.7	1169.8	188544.9	168508.6	2003.6

TABLE 5-4 (CONT.)
FOREST AREA (1000 HA) AND RATES OF CONVERSION (RC, 1000 HA/YR) FOR TROPICAL COUNTRIES

Central and South America and Caribbean

Countries	Dry			Montane Moist			Montane Dry		
	1980	1990	RC	1980	1990	RC	1980	1990	RC
Antigua and Barbuda									
Bahamas	58.7	47.3	1.1	7.8	6.3	0.2			
Bolivia	8261.6	7345.5	91.6	7253.1	6339.6	91.3	51.7	45.5	0.6
Brazil	31989.0	28862.5	312.6	49963.7	43565.2	639.9			
Belize				9.8	2.4	0.7			
Colombia	21.9	18.0	0.4	2971.8	2486.3	48.6	4.8	3.7	0.1
Costa Rica				1081.1	802.5	27.9			
Cuba	2.5	2.3	0.0	321.5	292.0	2.9	65.9	59.9	0.6
Dominica									
Dominican Republic				553.8	417.8	13.6	60.1	45.3	1.5
Ecuador	52.2	43.5	0.9	3716.6	3099.9	61.7			
El Salvador				98.5	78.5	2.0			
French Guyana									
Grenada									
Guadeloupe									
Guatemala				463.3	91.7	37.2	24.0		2.4
Guyana				1667.7	1667.7				
Haiti	0.0	0.0	0.0	14.6	9.0	0.6	1.6	1.0	0.1
Honduras				3442.4	2770.9	67.1	138.2	111.2	2.7
Jamaica	0.2	0.1	0.0	5.7	2.7	0.3	1.5	0.7	0.1
Martinique				0.0	0.0				
Mexico	1886.8	1590.3	29.6	9909.6	8903.9	100.6	25070.0	22356.8	271.3
Nicaragua				2356.1	1953.3	40.3			
Panama				1556.3	1248.6	30.8			
Paraguay	8305.2	6794.1	151.1	54.1	27.3	2.7			
Peru	22.8	18.8	0.4	15742.9	14692.3	105.1	102.0	84.9	1.7
Puerto Rico				104.6	120.5	-1.6			
St. Kitts and Nevis									
St. Lucia									
St. Vincent									
Surinam									
Trinidad and Tobago									
Venezuela	326.6	221.9	10.5	11400.2	10371.8	102.8	25.9	17.8	0.8
TOTAL	50927.5	44944.3	598.3	112695.2	98950.1	1374.5	25545.7	22726.8	281.9

Source: Data are from FAO (1993) and M. Lorenzini (pers. comm., 1996). Forest areas and rates of conversion are divided into the same land categories as in Box 2 and Table 5-1 in the *Reference Manual.*

TABLE 5-5
DRY MATTER IN ABOVEGROUND BIOMASS IN TROPICAL FORESTS
(TONNES DM/HA)

Tropical Forests						
	Wet	Moist with Short Dry Season	Moist with Long Dry Season	Dry	Montane Moist	Montane Dry
	R > 2000	2000>R>1000		R<1000	R>1000	R<1000
Africa	300	140	60-90	20-55	105	40
Asia: Continental	225	185	100	75	190	no data
Insular	275	175	no data	little to none exist	255	none exist
America	295	no data	90	105	150	50

R= annual rainfall in mm/yr.

Sources: See, *Reference Manual* (Table 5-4), additional biomass estimates for different forest types and disturbance classes, by climatic zones within countries are given in Table 5-5 in the *Reference Manual*

TABLE 5-6
DRY MATTER IN ABOVEGROUND BIOMASS IN TEMPERATE AND BOREAL FORESTS
(TONNES DM/HA)

Temperate Forests	Coniferous	220-295
	Broadleaf	175-250
Boreal Forests	Mixed broadleaf/coniferous	40-87
	Coniferous	22-113
	Forest-tundra	8-20

Sources: See Reference Manual

4 Subtract the figures in column C from the figures in column B to produce the figure for Net Change in Biomass Density in tonnes of dry matter per hectare and enter the result in column D.

5 Multiply the Area Converted Annually (in kilohectares) by the Net Change in Biomass Density (in tonnes per hectare) to calculate the Annual Loss of Biomass for each forest/grassland type in kilotonnes of dry matter (kt dm). Enter the results in column E.

STEP 2 ESTIMATING CARBON RELEASED BY BURNING ABOVEGROUND BIOMASS ON-SITE

1 Enter figures for the Fraction of Biomass Burned On Site by forest/grassland type in column F (see side-box).

2 Multiply the Annual Loss of Biomass (in kilotonnes) by the Fraction of Biomass Burned on Site to calculate the Quantity of Biomass Burned On Site (in kilotonnes of dry matter) for each forest/grassland type. Enter the result in column G.

3 Enter the Fraction of Biomass Oxidised on Site in column H (default fraction 0.9).

4 Multiply Quantity of Biomass Burned on Site (in kilotonnes of dry matter) by the Fraction of Biomass Oxidised on Site to calculate the Quantity of Biomass Oxidised on Site (in kilotonnes of dry matter). Enter the figures in column I.

5 Enter the Carbon Fraction of the Aboveground Biomass (burned on site) in column J (default value 0.5).

6 Multiply the Quantity of Biomass Oxidised on Site (in kilotonnes of dry matter) by the Carbon Fraction of the Aboveground Biomass to calculate the Quantity of Carbon Released (in kilotonnes carbon). Enter the results in column K.

7 Total the figures in column K and enter the figure in the Subtotal box at the bottom of column on the Worksheet.

This Subtotal will be used later to estimate emissions of other gases from burning on-site. (Worksheet 5-3)

FRACTIONS

Various fractions are used in calculating the emissions from forest/grassland conversion.

- Fraction biomass burned on-site and off-site.
- Fraction left to decay. This is the portion of the biomass which is simply left to decay and so releases gases at a slower rate.
- Fraction which oxidises during burning. This is the fraction of burned biomass which actually oxidises instead of turning to charcoal.

STEP 3 ESTIMATING CARBON RELEASED BY BURNING ABOVEGROUND BIOMASS OFF-SITE

1 Enter the Fraction of Biomass Burned off Site in column L.

2 Multiply the Annual Loss of Biomass (in kilotonnes of dry matter) from column E by the Fraction of Biomass Burned off Site to calculate the Quantity of Biomass Burned off Site (in kilotonnes of dry matter) for each forest/grassland type. Enter the result in column M.

3 Total the figures in column M and enter the figure in the Subtotal box at the bottom of the column on the Worksheet.

4 Enter the Fraction of Biomass Oxidised off Site for each forest/grassland type in column N (default value 0.9).

5 Multiply Quantity of Biomass Burned off Site (in kilotonnes of dry matter) by the Fraction Oxidised to calculate the Quantity of Biomass Oxidised off Site (in kilotonnes of dry matter). Enter the figures in column O.

6 Enter the Carbon Fraction of the Aboveground Biomass (burned off site) in column P (default value 0.5).

7 Multiply the Quantity of Biomass Oxidised off Site (in kilotonnes of dry matter) by the Carbon Fraction of the Aboveground Biomass to

calculate the Quantity of Carbon Released (in kilotonnes). Enter the results in column Q.

8 Total the figures in column Q and enter the figure in the Subtotal box at the bottom of the column on the Worksheet.

STEP 4 ESTIMATING TOTAL CARBON RELEASED BY BURNING ABOVEGROUND BIOMASS ON- AND OFF-SITE

1 Add the subtotal for the Quantity of Carbon released from Biomass Burned On-Site in column K to the subtotal for the Quantity of Carbon released (from Biomass Burned Off-Site) in column Q. The result is the Total Carbon Released (from on and off site burning). Enter the result in the Subtotal box at the bottom of column R.

STEP 5 ESTIMATING CO_2 RELEASED BY DECAY OF ABOVEGROUND BIOMASS

1 Enter figures for Average Area Converted (average over ten years) for each forest/grassland type in column A.

For default values, you can use Table 5-4 as the conversion rates are the average over the 10-year period 1980-1990.

2 Enter the average Biomass Before Conversion in tonnes of dry matter per hectare (t dm/ha) in column B. Default values are provided in Tables 5-5 and 5-6.

3 Enter the average Biomass After Conversion in tonnes of dry matter per hectare (t dm/ha) in column C. This figure includes any biomass not fully cleared (default value is 0) and biomass in agricultural use. (The default value is 10 tonnes dry matter per hectare.)

4 Subtract the value in column C from the value in column B to produce Net Change in Biomass Density in tonnes of dry matter per hectare. Enter the results in column D.

5 Multiply the Average Area Converted (10-Year Average) in kilohectares (column A) by the Net Change in Biomass Density in tonnes dry matter per hectare (column D) to calculate the Average Annual Loss of Biomass (aboveground) for each forest/grassland type in kilotonnes of dry matter (kt dm). Enter the results in column E.

6 Enter Fraction Left to Decay (10-Year average) in column F (see side-box).

7 Multiply the Average Annual Loss of Biomass for each forest/grassland type by the Fraction Left to Decay to calculate the Quantity of Biomass Left to Decay. Enter the result in column G.

8 Enter the Carbon Fraction in Aboveground Biomass in column H (default fraction 0.5).

9 Multiply the Quantity of Biomass Left to Decay (column G) by the Carbon Fraction (column H) to calculate Carbon Released from Decay of Aboveground Biomass. Enter the figures in column I.

10 Add the figures in column I and enter the total in the Subtotal box at the bottom of the column.

STEP 6 ESTIMATING TOTAL CO_2 EMISSIONS FROM FOREST AND GRASSLAND CONVERSION

1 Enter the total for Immediate Release from Burning (contained in the subtotal box of column R in Worksheet 5-2, sheet 3) in column A.

2 Enter the total for Delayed Emissions from Decay (contained in the subtotal box of column I in Worksheet 5-2, sheet 4) in column B.

3 Add the figures in columns A and B to calculate the Total Annual Carbon Release (in the Inventory Year from clearing over a 10 year period). Enter the result in column C.

4 Multiply the Total Annual Carbon Release by 44/12 to convert it into the Total Annual CO_2 Release (in Gg). Enter the result in column D.

ESTIMATING FRACTION LEFT TO DECAY

In the Amazon, *Fraction Left to Decay* is typically about 0.5 but this varies greatly by region. Country experts must provide this value.

There is a relationship between the fraction left to decay here and the fraction burned on and off site. For a given year the fraction burned, the fraction left to decay (and possibly a fraction harvested as commercial timber or other non-fuel use) should sum to 1.0, accounting for all biomass cleared. Because the burning and decay portions are averaged over different time periods in the methodology, the relationship need not be precise. However, assumptions made for these different fractions should be consistent.

Furthermore, in countries where fuelwood is critically short no wood may be left on site to burn or decay.

5.4 On-site Burning of Forests: Emissions of Non-CO_2 Trace Gases

5.4.1 Introduction

All burning of biomass (e.g., fuelwood, dung) for energy and of savannas and agricultural wastes is a significant source of CH_4, N_2O, CO and NO_x. Net CO_2 emissions from forest/grassland conversion were calculated in Section 5.3 above. Emissions of non-CO_2 trace gases from on-site burning of forests are calculated here.

5.4.2 Methodology

The method relies on estimation of the gross carbon flux based on work done in Section 5.3 of this *Workbook*.

CH_4 and CO are estimated as ratios to carbon fluxes emitted during burning. Total nitrogen content is estimated based on the nitrogen-carbon ratio. N_2O and NO_x are estimated as ratios to total nitrogen.

USING THE WORKSHEET

- Copy the Worksheet at the end of this section to complete the inventory.
- Keep the original of the Worksheet blank so you can make further copies if necessary.

Completing the Worksheet

Use WORKSHEET 5-3 ON-SITE BURNING OF FORESTS to enter data for this submodule.

STEP 1 ESTIMATING NITROGEN RELEASED

1 Enter the estimate of Quantity of Carbon Released from on-site burning of forests (in kilotonnes carbon) in column A.

Use the figure in column K of Worksheet 5-2, sheet 2, *Forest and Grassland Conversion*.

2 Enter the Nitrogen-Carbon Ratio of Biomass Burned in column B.

The general default value is 0.01.

3 Multiply Quantity of Carbon Released by the Nitrogen-Carbon Ratio to give the Total Nitrogen Released. Enter the total in kilotonnes of nitrogen in column C.

STEP 2 ESTIMATING NON-CO_2 TRACE GAS EMISSIONS

1 Enter Trace Gas Emissions Ratios in column D.

Refer to Table 5-7 for non-CO_2 trace gas emissions ratios.

TABLE 5-7
EMISSION RATIOS FOR OPEN BURNING OF FORESTS

Compound	Ratio
CH_4	0.012 (0.009-0.015)
CO	0.06 (0.04-0.08)
N_2O	0.007 (0.005-0.009)
NO_x	0.121 (0.094-0.148)

Note: Ratios for carbon compounds are mass of carbon released as CH_4 or CO (in units of C) relative to mass of total carbon released from burning (in units of C). Those for nitrogen compounds are expressed as the ratios of nitrogen released as N_2O and NO_x relative to the nitrogen content of the fuel (in units of N).

See *Reference Manual* for sources.

2 Multiply Quantity of Carbon Released (column A) by the emissions ratio for CH_4 to give the Amount of CH_4 released. Enter the amount in kilotonnes of C in column E.

3 Multiply Quantity of Carbon Released (column A) by the emissions ratio for CO to give the Amount of CO released. Enter the amount in kilotonnes of C in column E.

4 Multiply the Total Nitrogen Released (column C) by the emissions ratio for N_2O to give the Amount of N_2O Released. Enter the amount in kilotonnes of N in column E.

5 Multiply the Total Nitrogen Released (column C) by the emissions ratio for NO_x to give the Amount of NO_x Released. Enter the amount in kilotonnes of N in column E.

6 Multiply the figures in column E by the conversion ratios[1] in column F to give total for the release of CH_4, CO, N_2O and NO_x. Enter the results in Gg, which is the same as kilotonnes, in column G.

5.5 Abandonment of Managed Lands

5.5.1 Introduction

This submodule deals with net-CO_2 removals in biomass accumulation resulting from the abandonment of *managed* lands. Managed lands include:

- Cultivated lands (arable land used for the cultivation of crops)
- Pasture (land used for grazing animals)

Carbon accumulation on abandoned lands is sensitive to the type of natural ecosystem (forest type or grasslands) which is regrowing. Therefore abandoned lands regrowing should be entered by type. For grasslands the default assumption is that net accumulation aboveground is zero.

Because regrowth rates become slower after a time, the periods considered are:

- Land abandoned during the 20 years prior to the Inventory Year (i.e., 1990)
- Land abandoned between 20 and 100 years ago (i.e., before 1970 and after 1870)

When managed lands are abandoned, carbon may or may not reaccumulate on the land. Abandoned areas are therefore split into those which reaccumulate carbon and those which do not regrowth or which continue to degrade.

Only natural lands which are regrowing towards a natural state should be included. Lands which do not regrow or degrade should be ignored in this calculation.

As with forest and grassland conversion, effect of forest regrowth on soil carbon is dealt with in Section 5.6 of the *Workbook*.

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[1] The molecular weight ratios given above for the emitted gases are with respect to the weight of nitrogen and carbon in the molecule. Thus for N_2O the ratio is 44/28 and for NO_x it is 46/14. NO_2 has been used as the reference molecule for NO_x.

5.5.2 Methodology

Two sets of calculations are used to estimate CO_2 removals from biomass regrowth and soils recovery. They relate to the quantity of land abandoned and the length of time for which it has been abandoned:

- Annual carbon uptake in aboveground biomass (land abandoned in the last twenty years)
- Annual carbon uptake in aboveground biomass (land abandoned for between twenty and a hundred years, if applicable).

These are then totalled and the carbon uptake is converted into CO_2 removals.

Completing the Worksheet

Use WORKSHEET 5-4 ABANDONMENT OF MANAGED LANDS at the end of this module to record inventory data.

STEP 1 CALCULATE ANNUAL CARBON UPTAKE IN ABOVEGROUND BIOMASS (LAND ABANDONED IN THE LAST TWENTY YEARS)

1 Enter the Total Area Abandoned and Regrowing for the last twenty years (in kilohectares) in column A.

There are no default data for these figures.

2 Enter the Annual Rate of Aboveground Biomass Growth (in tonnes dry matter per hectare) in column B. See Table 5-8 for default values.

3 Multiply the Total Area Abandoned and Regrowing (column A) by the Annual Rate of Aboveground Biomass Growth (column B) to give the Annual Aboveground Biomass Growth (in kt dm). Enter the result in column C.

4 Enter the Carbon Fraction of Aboveground Biomass in column D (default fraction 0.5).

5 Multiply the Annual Aboveground Biomass Growth (column C) by the Carbon Fraction of Aboveground Biomass (column D) to give the Annual Carbon Uptake in Aboveground Biomass. Enter the result in column E.

6 Add the figures in column E and enter the total in the Subtotal box at the bottom of the column.

STEP 2 CALCULATE ANNUAL CARBON UPTAKE IN ABOVEGROUND BIOMASS (LAND ABANDONED FOR MORE THAN TWENTY YEARS)

1 Enter the Total Area Abandoned for more than Twenty Years (in kilohectares) in column G.

2 Enter the Annual Rate of Aboveground Biomass Growth (in tonnes of dry matter per hectare) in column H.

Table 5-8 provides default values.

3 Multiply the Total Area Abandoned (column G) by the Annual Rate of Aboveground Biomass Growth (column H) to give the Annual Aboveground Biomass Growth (in kt dm). Enter the result in column I.

4 Enter the Carbon Fraction of Aboveground Biomass in column J (default fraction 0.5).

5 Multiply the Annual Aboveground Biomass Growth (column I) by the Carbon Fraction of Aboveground Biomass (column J) to give the Annual Carbon Uptake in Aboveground Biomass. Enter the result in column K.

6 Add the figures in column K and enter the total in the Subtotal box at the bottom of the column.

STEP 3 CALCULATE TOTAL CO_2 REMOVALS FROM ABANDONED LANDS

1 Add the subtotals from columns E and K and enter the Total Carbon Uptake from Abandoned Lands in column L.

2 Multiply the Total Carbon Uptake from Abandoned Lands by 44/12 to give the Total Carbon Dioxide Uptake from the abandonment of managed lands in Gg. Enter the result in column M.

3 For summary reporting purposes and for consistency with other emission/removal categories, it is necessary to reverse the sign of these results, so that the removal of CO_2 by abandoned lands is expressed as a negative (i.e., negative emissions) value.

USING THE WORKSHEET

- Copy the Worksheet at the end of this section to complete the inventory.
- Keep the original of the Worksheet blank so you can make further copies if necessary.

TABLE 5-8
ANNUAL AVERAGE ABOVEGROUND BIOMASS GROWTH BY NATURAL REGENERATION
(TONNES DM/HA)

Tropical Forests

	Wet	Moist with Short Dry Season	Moist with Long Dry Season	Dry	Montane Moist	Montane Dry
	R ≥ 2000	2000>R>1000		R≤1000	R>1000	R<1000
Africa						
≤20 years	10	5.3	2.3-2.5	0.8-1.5	5	2
>20 years	2.5	1.3	0.6-3.0	0.2-1.6	1	0.5
Asia:						
Continental						
≤20 years	11	9	6	5	5	no data
>20 years	3	2	1.5	1.3	1	
Insular	13					
≤20 years	3.4	11	no data	little to	12	none exist
>20 years		3		none exist	3	
America						
≤20 years	10	no data	4	4	5	1.8
>20 years	2.6		1	1	1.4	0.4

Note: R= annual rainfall in mm/yr

Temperate Forests		0-20 Years	20-100 Years
	Coniferous	3.0	3.0
	Broadleaf	2.0	2.0
Boreal Forests		**0-20 Years**	**20-150 Years**
	Mixed Broadleaf-Coniferous and Broadleaf	0.7-2.0	0.7-6.4
	Coniferous	0.5-1.9	0.5-5.0
	Forest-tundra	0.2-0.5	

ALL OF THESE REGIONAL AVERAGE GROWTH RATES SHOULD BE CONSIDERED INDICATIVE ONLY. IF FORESTS ARE A SIGNIFICANT PART OF A COUNTRY'S TOTAL GREENHOUSE GAS INVENTORY, LOCALLY AVAILABLE DATA OR EXPERT JUDGEMENT SHOULD BE SOUGHT TO DEVELOP VALUES REFLECTING CONDITIONS AND PRACTICES.

See *Reference Manual* for sources.

5.6 CO_2 Emissions or Uptake by Soil from Land-Use Change and Management

5.6.1 Introduction

The methodology includes estimates of net CO_2 emissions (sinks and sources) from three processes: 1) changes in carbon stored in soil and litter of mineral soils due to changes in land-use practices, 2) CO_2 emissions from organic soils converted to agriculture or plantation forestry, and 3) CO_2 emissions from liming of agricultural soils. At present, CO_2 emissions or uptake associated with naturally ocurring carbonate minerals in soils are not included.

5.6.2 Data Sources

There are no standard global data sets available for these calculations. The primary data needed are information on the distribution of different soil types and land-use practices within a country. Information to estimate impacts of various land-use practices on soil carbon inventories can be obtained from long-term field experiments. Sources of such information include:

- Soil survey and other national resource inventories
- Land-use statistics, agricultural production statistics
- Compendia of long-term field experiments. (See *Reference Manual* for references.)

Information for estimating CO_2 emissions from lime applications can be obtained from statistics of lime use or derived from production and import-export statistics.

5.6.3 Methodology

The calculations for CO_2 emissions from mineral soils are based on an accounting of changes in soil (and litter) carbon stocks as a function of changes in land-use and agricultural management practices. To calculate changes in carbon stocks a twenty-year inventory period is used. This requires that an estimate of the distribution of land-use systems by soil types is needed for the present (i.e., inventory) year and for twenty years ago. See the *Reference Manual* for an example calculation. Estimates of soil carbon stocks are based on the top 30 cm of the soil profile only. Deeper soil layers can also have appreciable carbon stocks, particularly in tropical soils, but they are generally much less impacted by changes in land use/management than are topsoil layers and there are less data available for deeper soil layers.

The calculations for CO_2 emissions from organic soils are performed using annual emission estimates which depend on climate region and landuse. Thus they require data on the areal extent of organic soils which are presently used and their current landuse. The emission rates provided in the method are derived from a world-wide survey of the scientific literature.

The calculations for emissions from agricultural liming require only data on the amount and (preferably) the type of material applied.

Completing the Worksheets

Use WORKSHEET 5-5 CHANGE IN SOIL CARBON FOR MINERAL SOILS at the end of this module to record inventory data.

LAND-USE MANAGEMENT SYSTEMS

These should represent the major types of land management systems present in the country as well as ecosystem types which are either being converted to agriculture (e.g., forest, savanna, grassland) or have been derived from previous agricultural landuse (e.g., abandoned lands, reforested lands). Systems should also reflect differences in soil carbon stocks that can be related to differences in management. For shifts in management where changes in carbon stocks occur over a relatively long time (i.e., > 10 years), one or more "successional" systems (e.g., young abandoned land, old abandoned land) should be defined (see Step 2). Examples of default management systems for different climatic regions are given in the Appendix.

STEP 1 ESTIMATING THE DISTRIBUTION OF LAND-USE/MANAGEMENT SYSTEMS BY SOIL TYPES (FOR MINERAL SOILS ONLY) FOR THE BEGINNING AND END OF THE INVENTORY PERIOD

1 Define the types of land-use management systems to be used in the inventory.

2 Enter the Land-use/Management System in column A.

Worksheet 5-5, sheet 1 should be copied as needed to accommodate all the management systems used in the inventory (see Appendix in the Workbook and Table 5-10 in *Reference Manual* for an example).

3 Enter the Land Area in column E for each system subdivided by soil type in million hectares for the current inventory year (t).

If a land-use system does not occur on a particular soil type, a zero ("0") should be entered.

4 Enter the Land Area in column D for the inventory year, (t-20), i.e., twenty years prior to the current inventory year.

Note: The total areas for each soil type (summed over all land-use systems) in year, t, and year, t-20, must be the same. As a check, sum values in column D over all land-use systems. Repeat for all values in column E. The sums for columns D and E must be identical (i.e. equal to the total land area in the inventory).

STEP 2 ASSIGN CARBON STOCK VALUES ACCORDING TO LAND-USE/MANAGEMENT SYSTEM AND SOIL TYPE

1 For <u>native ecosystem types</u>, enter the Soil Carbon values into column C in tonnes C/ha. Table 5-9 shows default values.

In cases where the ecosystem is agriculturally-impacted, use the Supplemental Worksheet 5-5A to estimate soil carbon instead.

For agriculturally-impacted systems the following equation is used:

$$\text{Soil Carbon}_{managed} = \text{Soil Carbon}_{native} \times \text{Base factor} \times \text{Tillage factor} \times \text{Input factors}$$

<u>Worksheet 5-5A (Supplemental):</u> SOIL CARBON FOR AGRICULTURALLY IMPACTED LANDS.

1 Enter the Land-use/Management System in column A, as identified in Step 1 of Worksheet 5-5.

Worksheet 5-5A (supplemental) should be copied as needed to accommodate <u>all</u> the management systems.

2 Enter Soil Carbon under Native Vegetation into column C. Table 5-9 provides default values.

3 Enter the Base Factor into column D. Table 5-10 provides default values.

4 Enter the Tillage Factor into column E. Table 5-10 provides default values. Where no default or country-specific data are available, enter 1.

5 Enter Input Factors into column F. Table 5-10 provides default values. Where no default or country-specific data are available, enter 1.

6 Multiply the values in columns C, D, E and F. Enter these values into column G to obtain the Soil Carbon into Agriculturally-Impacted Lands.

7 Enter the values in column E into column C of Worksheet 5-5, sheet 1.

DEFAULT TILLAGE AND INPUT FACTORS

Default Tillage and Input Factors, can be found in Table 5-10, according to the default definitions of Land-Use Management Systems shown. Please note that the all definitions found in the Appendix can be categorised under the default definitions summarised in Table 5-10.

TABLE 5-9
APPROXIMATE SOIL CARBON CONTENTS
UNDER NATIVE VEGETATION
(TONNES C/HA FOR 0-30 CM DEPTH)

Region	High activity soils	Low activity soils	Sandy soils	Volcanic soils (Andisols)	Wetland soils (Aquic)
Cold temperate, dry	50	40	10	20	70
Cold temperate, moist	80	80	20	70	180
Warm temperate, dry	70	60	15	70	120
Warm temperate, moist	110	70	25	130	230
Tropical, dry	60	40	4	50	60
Tropical, moist-long dry season	100	50	5	70	100
Tropical, moist-short dry season	140	60	7	100	140
Tropical, wet	180	70	8	130	180

TABLE 5-10[a]
COEFFICIENTS USED IN DEFAULT CALCULATION PROCEDURES

System	SG[b]	BF	Tillage Factor[c]			Input Factors[d]				
Temperate			No tillage	Red. tillage	Full tillage	Low input	Med. input	High input	Mature fallow	Shortened fallow
Long-term cultivated	A,B,C,D	0.7	1.1	1.05	1.0	0.9	1.0	1.1/1.2		
Long-term cultivated	E	0.6	1.1	1.05	1.0	0.9	1.0	1.1/1.2		
Improved pasture	All soils	1.1				ND	ND	ND		
Set aside (<20 years)	All soils	0.8				ND	ND	ND		
Set aside (>20 years)	All soils	0.9				ND	ND	ND		
Tropical										
Long-term cultivated	A,B,C,D	0.6	1.1	1.0	0.9	0.8	0.9	1.1/1.2		
Long-term cultivated	E	0.5	1.1	1.0	0.8	0.8	0.9	1.1/1.2		
Wetland (Paddy) rice	All soils	1.1	ND	ND	ND	ND	ND	ND		
Shifting cultivation (including fallow)	All soils	0.8	ND	ND	ND	ND	ND	ND	1.0	0.8
Abandoned/ Degraded land	All soils	0.5								
Unimproved pasture	All soils	0.7				ND	ND	ND		
Improved pasture	All soils	1.1				ND	ND	ND		

[a] Filled portions of the table, where tillage and input factors are not given, denote instances where these factors are not applicable to a management system. Where tillage or input factors were not determined (ND), information was deemed insufficient to go beyond estimating a base factor.

SG = Soil Group, BF = Base Factor, Red. = Reduced, Med. = Medium.

[b] Soil groups A = High activity, B = Low activity, C = Sandy, D = Volcanic, E = Aquic

[c] Use of no-till is assumed to increase soil C by over full tillage (full soil inversion). Reduced tillage (i.e., significant soil disturbance but without inversion) is assumed to yield small increases over full tillage.

[d] Input factors apply to residue levels and residue management, use of cover crops, mulching, agroforestry, bare fallow frequency in semi-arid temperate systems. Low input applies to where crop residues are removed or burned, or use of bare fallow; medium input to where crop residues are retained; high input applies to where residue additions are significantly enhanced with addition of mulches, green manures, or enhanced crop residue production (1.1) or regular addition of high rates of animal manure (1.2), relative to the nominal (medium) case.

STEP 3 CALCULATING NET ANNUAL EMISSIONS FROM MINERAL SOILS.

1 Multiply the Soil Carbon value in column C by the Land Area in column D. Enter this value in column F.

2 Multiply the Soil Carbon value in column C by the Land Area in column E. Enter the value in column G.

3 Subtract the value in column F from column G. Enter this value in column H for the Net Change in Soil Carbon in Mineral Soils for each landuse by soil type.

Negative values represent net losses of carbon and positive values are net gains in stored carbon.

4 Sum values in the column H over all land-use/management systems and enter this value at the bottom of column H.

ORGANIC SOILS UNDER INTENSIVE USE

Emissions of CO_2 from organic soils are only considered for soils which are currently under **intensive** use for crop production or plantation forestry. Organic soils under native ecosystem types (which are likely to have stable or increasing C stocks) are **not** to be included in the inventory.

STEP 4 CALCULATING ANNUAL EMISSIONS FROM ORGANIC SOILS

1 Enter the Land Area (in hectares) of organic soils into column A of Worksheet 5-5, sheet 2, for the appropriate climate zone (see Appendix for climate zone definitions) and soils use.

2 Enter the Annual Loss Rate in column B. Default values are provided in Table 5-11. Use country specific data where available.

3 Multiply the Land Area in column A by the Annual Loss Rate in column B and enter this value in column C.

4 Sum the values in column C and enter this value at the bottom of the column.

STEP 5 CALCULATING ANNUAL EMISSIONS FROM LIMING OF AGRICULTURAL SOILS

1 Enter the Total Annual Amount of Lime (country-wide), into column A of Worksheet 5-5, sheet 3, according to the type of lime. If information is not available on the type of lime applied, assume all lime to be limestone ($CaCO_3$).

2 Multiply values in column A by the Carbon Conversion Factors in column B and enter these values in column C.

3 Sum the values in column C and enter at bottom of the column.

STEP 6 ESTIMATES FOR TOTAL NET EMISSIONS FROM SOILS

1 Enter the Total Net Change in Soil Carbon in Mineral Soils from all Worksheets 5-5, sheet 1, into column A (first row).

2 Enter the Total Net Carbon Loss from Organic Soils from all Worksheets 5-5, sheet 2 into column A (second row).

3 Enter the Carbon Emissions from Liming from Worksheet 5-5, sheet 3 into column A (third row).

4 Multiply the values in column A by Unit Conversion Factors in column B to express all values as Total Annual Carbon Emissions in Gigagrams per year. Enter these values in column C.

Note that the explicit sign (i.e., + or -) for the change of carbon stocks for mineral soils must be carried over from Worksheet 5-5, sheet 1.

5 Multiply each value in column C by 44/12 and enter in column D.

6 Sum all values in column D and enter in the bottom of the column to obtain the (net) Total Annual CO_2 Emissions from agriculturally-impacted soils.

TABLE 5-11
DEFAULT VALUES FOR CARBON LOSS FROM ORGANIC SOILS

Agricultural Use of Organic Soils	Annual Loss Rate (MgC/ha/yr)
Cool temperate	
Upland crops	1.0
Pasture/Forest	0.25
Warm temperate	
Upland crops	10
Pasture/Forest	2.5
Tropical	
Upland crops	20
Pasture/Forest	5

Appendix: Default Definitions of Land-Use/Management Systems

1. COLD TEMPERATE, DRY

Characterised by mean annual temperature (MAT) of < 10°C and annual precipitation less than evapotranspiration. Crop production is limited by inadequate water, and by a relatively short growing season and harsh winters which restrict the choice of crops. **Includes the following areas: northern portion of the Great Plains of North America, and extensive areas in central and eastern Asia.**

a) Rangeland (unimproved): grassland, often dominated by native species, used to support grazing livestock (chiefly cattle) at comparatively low intensity. Usually receive only minimal inputs for fertility amendment or pest control.

b) Small grain with summer-fallow: predominantly spring annuals (e.g., wheat, barley, flax, rapeseed/canola) grown in a sequence with periodic summer-fallow (a practice, used to replenish soil moisture and nutrients, whereby land is left unplanted for an entire growing season and weeds are controlled by tillage and/or herbicide application). Soils typically receive only minor inputs of nutrients and other amendments.

c) Small grain with continuous cropping - conventional tillage: predominantly spring annuals, either in monoculture or in various combinations (including wheat, barley, oats, flax, canola, rye, mustard, lentil, pea). Continuous cropping requires higher inputs of nutrients than cropping systems with summer fallow. Weed control is achieved using herbicides (during growing season) in combination with tillage in spring and/or fall.

d) Small grain with continuous cropping - no till: predominantly spring annuals, either in monoculture or in various combinations (including wheat, barley, oats, flax, canola, rye, mustard, lentil, pea). Continuous cropping requires higher inputs of nutrients than cropping systems with summer fallow. Weed control is achieved using only herbicides, and crops are seeded without prior tillage directly into residues remaining from the previous crop.

e) Small grain/forage rotations: predominantly perennial grasses or legumes, interrupted periodically by several consecutive annual crops (typically spring-seeded cereals or oilseeds). A typical rotation might be five to 10 years in length. As this system is often used in concert with livestock production, significant amounts of nutrients may be returned in manures.

f) Hay/improved pasture: predominantly perennial legumes and grasses maintained for extended periods of time, primarily as a forage. The forages are typically non-native species, introduced because of their comparatively high productivity.

g) Successional grasslands: previously cultivated land which has been returned to grassland, but has not yet attained characteristics of native rangeland. Usually a single species or mixture of grasses established either through land abandonment or as part of a government program, often to stabilise degrading lands or to reduce cultivated areas in the wake of surplus production.

h) Irrigated cropping systems: typically include wide diversity of relatively high value crops adapted to short-growing seasons, including spring-seeded cereals and oilseeds, high-value forages, and vegetables (e.g., potatoes, root crops, vegetables). Owing to the high cost of irrigation, the cropping systems usually involve high inputs of nutrients and other amendments to maximise yield and crop quality.

2. COLD TEMPERATE, MOIST

Characterised by MAT < 10°C and annual precipitation similar to or higher than evapotranspiration. Crop production is limited by the short growing season and relatively harsh winters. Inadequate temperature to support heat-requiring feedgrains such as maize and soybean; production dominated by small grain cereals, forages, root crops. **Includes most of Scandinavia, Finland, and parts of Russia and North America.**

a) Forest: natural vegetation includes deciduous forest and Taiga (coniferous forest); often interspersed with wetlands (peat bogs). Relatively young soils due to glaciation; many acid with thick litter layer (podzols).

b) Small grain monocultures: predominantly wheat but also barley, oats, rye, rapeseed (canola) grown annually. Full tillage (plough) generally used. Often highly fertilised and high-yielding, 5-10 t/ha. On some minor areas, a full year bare-fallow may be used at irregular intervals; earlier used more commonly for weed control (prior to herbicides).

c) Grain/perennial forage crop rotations: small grains and rapeseed grown in rotation with grass and legume forages, also root crops. Typical for mixed farms with livestock, including dairy production.

d) Permanent pasture: used for grazing and/or hay production. Generally on soils or in climate zones which are unsuitable for intensive crop production (e.g., common in Northern Scandinavia and Finland).

e) Grassland and forest set-aside lands: grassland area very fluctuating between years due to varying subsidy policies. Short-term rotation forest for bioenergy is increasing.

3. WARM TEMPERATE, DRY

Mean annual growing season temperatures in this zone usually range from 10 to 20°C with annual precipitation usually less than 600 mm; includes continental and Mediterranean climates. Includes major grain and livestock producing areas in the Great Plains and Pacific Northwest in the United States, Mediterranean regions in Australia, Europe and South Africa, and the semi-arid belt across southern Russia, central Asia and China.

a) Pastoral rangelands: unimproved grassland, often dominated by native species, used to support grazing livestock (cattle and sheep) at comparatively low intensity. Fertiliser additions and pest control are virtually non-existent.

b) Small grain with summer-fallow (or long-fallow): predominantly small grains (usually high value wheat) with a year of bare fallow to replenish soil moisture and nutrients. This practice is most prevalent in the driest areas, e.g., where annual precipitation may be less than 400 mm. Weeds are controlled by tillage, herbicide application (increasing with use of no-till), and animal grazing (e.g., sheep in Australia). Inputs of nutrients and other amendments often low compared to more continuous cropping and erosion and soil degradation can be high due to lengthy bare fallowing.

c) Small grain/legumes with summer-fallow: Legumes in the form of chick or field peas, lupin and faba beans, are grown in rotation with grain. This system requires less fertiliser inputs than small grains only due to N fixation by the legume. The potential for soil loss through erosion is usually increased after grain legumes such as field and chick peas as they tend to provide less residue cover compared to other crops.

d) Small grain with continuous cropping - conventional tillage: Includes small grains in monoculture (wheat, barley) but increasingly more diverse crop rotations are being used (e.g., triticale, mustard, canola, sunflower, maize, sorghum, millet). These system require a higher input of nutrients and are more common in higher precipitation zones (> 400 mm).

e) Small grain with continuous cropping - no till: Similar crops as listed above for conventionally tilled systems, but use of no-till can increase efficiency of water use and extend the use of more continuous cropping regimes to lower rainfall areas. Greater surface residue levels help control erosion.

f) Small grain with hay/improved pasture: The typical rotation may include one or two consecutive years of sown annual pasture or hay. A long-fallow may also be included prior to the cereal phase. However, this practice is being phased out and its use is restricted to marginal cropping regions. Organic carbon levels have been found to increase quite dramatically as has aggregate stability with well-managed pastures. Rotations of two years cereal and 2-4 years pasture have been used but are usually non-economical.

g) Successional grasslands: previously cultivated land which has been returned to grassland, but has not yet attained characteristics of native rangeland. Usually a single species or mixture of grasses established either through land abandonment or as part of a government programme, often to stabilise degrading lands or to reduce cultivated areas in the wake of surplus production.

h) Irrigated cropping systems: may include a wide diversity of related crops, including major field crops (maize, wheat, rice, cotton) as well high value vegetable crops. The cropping systems usually involve high inputs of nutrients and other amendments to maximise yield and crop quality.

4. WARM TEMPERATE, MOIST

Mean annual growing season temperatures in this zone usually range from 10-20°C and with annual precipitation near or exceeding potential evapotranspiration. Soils in this region include young glacial-derived soils grading into more highly weathered soils in warmer (lower latitude) regions. This zone is dominated by intensively managed, highly productive agricultural systems. **Includes the central latitudes of western and eastern Europe, south-eastern Russia, parts of China, Korea, Japan, the central and eastern United States, and parts of Australia, New Zealand and South America.**

a) Forest: the dominant native ecosystem is temperate deciduous forest, as well as some areas of humid grasslands and temperate coniferous forests especially where impacted by frequent fires. Native grasslands in this area have been almost exclusively converted to permanent agriculture as have large areas of formerly forested lands. Similarly, significant areas of formerly cultivated areas have been abandoned and reverted to forest, particularly in the United States.

b) Pasture/hay: permanent pastures which are either grazed and/or harvested for hay. Can occupy a significant land area in dairy and livestock producing areas and also occur on areas which have limitations for use as cropland, including hilly terrain and areas with poor drainage.

c) Intensive grain production: dominated by production of food and feedgrains for trade, including maize, soybean, wheat, oats as well as potato and root crops. In general these systems receive high inputs of fertiliser and other agrochemicals and are highly mechanised. For inventory purposes, sub-classification into systems according to organic matter inputs (and residue management) and tillage practices is recommended.

   - Contrasting carbon input level-high residue input systems would include one or more of the following practices: significant manure or sewage sludge applications, crop rotations which include multiple years of perennial hay crops, double-cropping, and use of winter cover crops that are returned to the soil. Nominal input systems would include grain production systems with normal rates of fertilisation and residues returned to the soil. Low residue input systems would include grain production where residues are removed from the soil.

   - Tillage practices - separate categories could be included for no-till, reduced tillage and full (intensive tillage). Reduced tillage would include practices with infrequent and minimal and shallow soil disturbance. Full tillage refers to tillage where there is substantial soil inversion and mixing (e.g., moldboard ploughing) of the A horizon as well as secondary tillage.

d) Speciality crop production: includes systems which are dominated by intensively managed non-grain crops, such as tobacco, cotton, peanuts, truck (vegetable) crops, in which most of the biomass produced is removed from the field or where there is otherwise low rates of residues returned.

e) Reverted land: includes former agricultural land which has been taken out of production and either converted or allowed to revert to perennial grass or forest vegetation. Subdivisions according to "age classes" or successional stages is recommended for specifying soil carbon contents.

5. TROPICAL, DRY

Characterised by MAT above 20°C and annual precipitation generally below 1000 mm with a long and pronounced dry season that results in a growing season of limited length. Soils are highly variable, e.g., high activity Vertisols (India) Lateritic Alfisols (Africa) and highly acid Alfisols and Oxisols (South America). Average productivity for most common crops is low, not only due to water deficiency but also due to nutrient deficiencies which are not corrected by fertilisation because fertiliser investment is risky in a drought-prone zone.

a) Savanna: the natural vegetation climax in this zone. The cover by woody plants can range from none to virtually complete, although the average is less than 30 per cent. Increases in woody cover often result from sustained grazing pressure and the exclusion of fire; depletion of woody cover results from unsustainable demand for firewood. The carbon density of the system is strongly affected by the amount of tree cover, both through the tree biomass and through elevated soil organic matter below the canopy. Main use is grazing. In grass-dominated regions, extensive grazing of cattle with no pasture management (e.g., Llanos in Venezuela and Colombia). Productivity is low (stocking rates at 10-20 ha/animal) and endangered by overgrazing and desertification. In grass and shrub regions, extensive grazing and migratory herding with no management and often serious overstocking with cattle, goats and sheep (e.g., Sahel) occurs.

b) Subsistence farming with drought-resistant grain crops: millet and sorghum are staples for subsistence farmers, who may also plant maize in wetter years. Includes Latifundia in which slash-burning and arable production relies on sharecroppers. Mixed cropping with 5-10 intercropped crops is typical. After 3-8 years of cropping, areas are rotated through bush fallow, which is often extensively grazed or browsed. Common throughout the South American and Southern African dry zone. An African variant of Latifundia is village-owned land where arable use rights are conferred to families. This system has shown great stability (>600 years in West Africa) but is crumbling under population pressure. Also includes small owner-operator farms that rely on family labour. When yields are low, rotation of cropped areas requires a large landholding to permit bush fallowing or, otherwise land may be abandoned in shifting cultivation.

c) Irrigated cropping: where river or groundwater are available, a wide range of cash crops can be grown, including maize, sugarcane, citrus and tropical fruits, vegetables, tobacco and cotton.

6 and 7. TROPICAL, MOIST WITH LONG, AND SHORT DRY SEASONS

MAT above 20°C and annual precipitation between 1000 to 2000 mm. Can be subdivided into regions with long dry season (> 5 months) versus short dry season of < 5 months. Production varies with precipitation amount and dry season length with an increasing importance of high input, mechanised agriculture in the more humid areas on suitable soils. Crop production is seasonal but two crops can often be produced in a year in more humid areas. The soils in the drier regions may be more fertile, and with higher pH, due to less weathered soils. **These zones includes large areas of Africa, the majority of the India subcontinent and continental Southeast Asia, and pockets in Latin America and Australia.**

a) Forests: vegetation is often described as tropical deciduous, or tropical dry forests, the canopy becoming more completely deciduous as the length of the dry season increases, fires are common in drier habitats and mixtures of deciduous and evergreens occur at the wetter extreme.

b) Unimproved grazing: extensive livestock grazing, often in combination with crop production on adjacent areas in subsistence agriculture, where manure from grazing livestock is utilised.

c) Improved grazing: at the higher end of the rainfall range, pastures may be improved through species selection, weed control, and fertilisation, and reach higher productivity.

d) Shifting cultivation and fallow rotation systems: burns are more complete than the more humid regions due to prolonged dry seasons resulting in more biomass combusted and lower carbon stocks, a cropping phase (2-3 years) may be longer with respect to the fallow phase (10 years) as compared to more humid regions but fallow reaccumulation is slower particularly on infertile soils. Much of the land in Africa has shifted to more continuous cultivation while large tracts of Southeast Asia and India could still be classified as shifting cultivation. In some cases, lands have degraded due to increasingly short fallow intervals and derived savannas have replaced natural succession to deciduous forest.

e) Mixed continuous cropping (manual): this is the most prevalent land use in this zone in Africa and has replaced large areas of land previously used for shifting agriculture over the past 50 years. These farming systems occupy some of the most densely populated agricultural landscapes in the tropics consisting of mixtures of annual field crops (maize, beans) and perennials (banana, coffee, sugarcane). Crop residues are regarded as an important component of yield as animal feed to confined livestock but manure and composting strategies are often very advanced. Nonetheless, soil carbon stocks in highland cropping systems have dropped to less than 50 per cent of their original levels.

f) Mechanised continuous cropping (residue management): continuous mechanised cropping became a major land use in Asia with the advent of the Green Revolution. Major crops are rice and wheat, and the degree of residue return varies greatly with either burning residues and complete removal for animal feed common, but a trend toward residue incorporation is increasing as burning is prohibited. Some parts of Latin

America have converted native deciduous forest to mechanical continuous cultivation of soybean, rice and maize.

g) Plantations: the plantations of the tropics are generally located in this zone and the subhumid zone with a shorter dry season, teak plantations being the most renowned. Other plantations include coffee, tea and pineapple. One trend which has reduced carbon stocks in coffee is the conversion of shade coffee, with its accompanying shade trees, to sun grown coffee.

h) Irrigated cropping: can include crops similar to that described for the semi-arid zone as well as wetland rice. Only one crop per year of wetland rice is possible where there is an extended dry season. This is probably the dominant cropping system in India and Southeast Asia but is seldom found in Africa or Latin America.

8. TROPICAL, WET

Characterised by MAT of above 20°C and annual precipitation > 2000 mm, with no significant dry season. Crop production is generally limited by low soil fertility and soil acidity on heavily leached soils and/or by rapid invasion of weeds such as Imperata. Exceptions are the fertile soils of recent volcanic origin and the rice paddies, which often benefit from sediments eroded from the uplands. Perennial-based production systems are the most sustainable land use. **Covers substantial parts of South America (the Amazon basin), equatorial Africa and Southeast Asia.**

a) Forest: the natural climax vegetation in this zone, with the highest biodiversity of the world. Forest degradation and soil damage can occur due to logging impacts, especially on skidding trails and roads; non-climax natural vegetation often occurs in mosaics with “shifting cultivation” and is dealt with under that category.

b) Agroforests and other mixed perennial (multi-strata) systems: human-made, diverse forest-like vegetation with a mixture of useful trees and elements of the natural vegetation; ecological functions, such as soil C storage, are close to those of natural secondary forests of similar age; this land use category is often not (yet) recognised in the available statistics.

c) Intensive upland food crop production with all crop residues maintained: mechanised or based or human labour, intensive food crop production while retaining all crop residues and providing sufficient nutrient inputs can maintain adequate soil organic matter levels and meet sustainable production targets. This group includes intensive vegetable production at higher elevations, unless soil erosion is dominant.

d) Monoculture plantations of perennial crops: monospecific stands of perennial crops (e.g., industrial trees, rubber, oil palm, coconut, sugarcane, pineapple); generally intermediate levels of soil organic matter, depending on residue management. Substantial differences in soil organic carbon with sugarcane occur, as on part of the area all residues are (still) burned after harvest, while on others they are incorporated into the soil.

e) Shifting cultivation and fallow rotation systems: a very broad group of land-use systems, based on a few years of crop production with declining soil organic carbon contents and a "recovery" fallow period of a few years (short (bush) fallow rotation systems) or longer (long fallow rotation and classical shifting cultivation, based on secondary forest succession). Calculations of C stocks should be based on a weighted average of the currently cropped fields and the fallow vegetation. In Southeast Asia, the system can be an early stage of "agroforest" development, but can also lead to "degraded grasslands".

f) Improved pastures: with the use of introduced grasses, a sufficient legume component, adequate soil fertility maintenance and carefully managed animal stocking rates, soil organic carbon can be maintained close to that of the forests which were replaced.

g) Degraded pastures and frequently burnt grasslands: low amounts of organic inputs due to burning or physical damage to the standing vegetation lead to a decrease in soil organic carbon.

h) Wetland or paddy rice fields, on a range of soils: variation occurs in the number of rice crops per year, the presence or absence of a dry period (with or without dryland food crops) during which soil organic carbon decomposes rapidly, and the burning, removal or incorporation of crop residues will affect organic carbon levels.

		MODULE	LAND USE CHANGE AND FORESTRY				
		SUBMODULE	CHANGES IN FOREST AND OTHER WOODY BIOMASS STOCKS				
		WORKSHEET	5-1				
		SHEET	1 OF 3				
			STEP 1				
			A Area of Forest/Biomass Stocks (kha)	B Annual Growth Rate (t dm/ha)	C Annual Biomass Increment (kt dm)	D Carbon Fraction of Dry Matter	E Total Carbon Uptake Increment (kt C)
					C=(A x B)		E=(C x D)
Tropical	Plantations	*Acacia spp.*					
		Eucalyptus spp.					
		Tectona grandis					
		Pinus spp					
		Pinus caribaea					
		Mixed Hardwoods					
		Mixed Fast-Growing Hardwoods					
		Mixed Softwoods					
	Other Forests	Moist					
		Seasonal					
		Dry					
	Other (specify)						
Temperate	Plantations	Douglas fir					
		Loblolly pine					
	Commercial	Evergreen					
		Deciduous					
	Other						
Boreal							
Non-Forest Trees (specify type)			A Number of Trees (1000s of trees)	B Annual Growth Rate (kt dm/1000 trees)			
						Total	

MODULE	**LAND USE CHANGE AND FORESTRY**
SUBMODULE	**CHANGES IN FOREST AND OTHER WOODY BIOMASS STOCKS**
WORKSHEET	**5-1**
SHEET	**2 OF 3**

	STEP 2							
Harvest Categories (specify)	F Commercial Harvest (if applicable) (1000 m^3 roundwood)	G Biomass Conversion/ Expansion Ratio (if applicable) (t dm/m^3)	H Total Biomass Removed in Commercial Harvest (kt dm)	I Total Traditional Fuelwood Consumed (kt dm)	J Total Other Wood Use (kt dm)	K Total Biomass Consumption (kt dm)	L Wood Removed From Forest Clearing (kt dm)	M Total Biomass Consumption From Stocks (kt dm)
			H = (F x G)	FAO data		K = (H + I + J)	(From column M, Worksheet 5-2, sheet 3)	M = K - L
Totals								

MODULE	**LAND USE AND FORESTRY**
SUBMODULE	**CHANGES IN FOREST AND OTHER WOODY BIOMASS STOCKS**
WORKSHEET	**5-1**
SHEET	**3 OF 3**

STEP 3		**STEP 4**	
N Carbon Fraction	O Annual Carbon Release (kt C)	P Net Annual Carbon Uptake (+) or Release (-) (kt C)	Q Convert to CO_2 Annual Emission (-) or Removal (+) (Gg CO_2)
	O = (M x N)	P = (E - O)	Q = (P x [44/12])

MODULE		LAND-USE CHANGE AND FORESTRY				
SUBMODULE		FOREST AND GRASSLAND CONVERSION - CO_2 FROM BIOMASS				
WORKSHEET		5-2				
SHEET		1 OF 5 BIOMASS CLEARED				
		STEP 1				
Vegetation types		A Area Converted Annually (kha)	B Biomass Before Conversion (t dm/ha)	C Biomass After Conversion (t dm/ha)	D Net Change in Biomass Density (t dm/ha)	E Annual Loss of Biomass (kt dm)
					D = (B - C)	E = (A x D)
Tropical	Wet/Very Moist					
	Moist, short dry season					
	Moist, long dry season					
	Dry					
	Montane Moist					
	Montane Dry					
Tropical Savanna/Grasslands						
Temperate	Coniferous					
	Broadleaf					
Grasslands						
Boreal	Mixed Broadleaf/ Coniferous					
	Coniferous					
	Forest-tundra					
Grasslands/Tundra						
Other						
Subtotals						

MODULE	LAND-USE CHANGE AND FORESTRY	
SUBMODULE	FOREST AND GRASSLAND CONVERSION - CO_2 FROM BIOMASS	
WORKSHEET	5-2	
SHEET	2 OF 5 CARBON RELEASED BY ON-SITE BURNING	

Vegegation types		STEP 2 F Fraction of Biomass Burned on Site	G Quantity of Biomass Burned on Site (kt dm)	H Fraction of Biomass Oxidised on Site	I Quantity of Biomass Oxidised on Site (kt dm)	J Carbon Fraction of Above-ground Biomass (burned on site)	K Quantity of Carbon Released (from biomass burned) (kt C)
			G = (E x F)		I = (G x H)		K = (I x J)
Tropical	Wet/Very Moist						
	Moist, short dry season						
	Moist, long dry season						
	Dry						
	Montane Moist						
	Montane Dry						
Tropical Savanna/Grasslands							
Temperate	Coniferous						
	Broadleaf						
Grasslands							
Boreal	Mixed Broadleaf/Coniferous						
	Coniferous						
	Forest-tundra						
Grasslands/Tundra							
Other							
						Subtotal	

	MODULE	**LAND-USE CHANGE AND FORESTRY**						
	SUBMODULE	**FOREST AND GRASSLAND CONVERSION - CO_2 FROM BIOMASS**						
	WORKSHEET	**5-2**						
	SHEET	**3 OF 5 CARBON RELEASED BY OFF-SITE BURNING**						
		STEP 3						**STEP 4**
Vegetation types		L Fraction of Biomass Burned off Site	M Quantity of Biomass Burned off Site (kt dm)	N Fraction of Biomass Oxidised off Site	O Quantity of Biomass Oxidised off Site (kt dm)	P Carbon Fraction of Above-ground Biomass (burned off site)	Q Quantity of Carbon Released (from biomass burned off site (kt C)	R Total Carbon Released (from on and off site burning) (kt C)
			M = (E x L)		O = (M x N)		Q = (O x P)	R = (K + Q)
Tropical	Wet/Very Moist							
	Moist, short dry season							
	Moist, long dry season							
	Dry							
	Montane Moist							
	Montane Dry							
Tropical Savanna/Grasslands								
Temperate	Coniferous							
	Broadleaf							
Grasslands								
Boreal	Mixed Broadleaf/ Coniferous							
	Coniferous							
	Forest-tundra							
Grasslands/Tundra								
Other								
		Subtotals						

MODULE	**LAND-USE CHANGE AND FORESTRY**
SUBMODULE	**FOREST AND GRASSLAND CONVERSION - CO_2 FROM BIOMASS**
WORKSHEET	**5-2**
SHEET	**4 OF 5 CARBON RELEASED BY DECAY OF BIOMASS**

Vegetation types		A Average Area Converted (10 Year Average) (kha)	B Biomass Before Conversion (t dm/ha)	C Biomass After Conversion (t dm/ha)	D Net Change in Biomass Density (t dm/ha)	E Average Annual Loss of Biomass (kt dm)	F Fraction Left to Decay	G Quantity of Biomass Left to Decay (kt dm)	H Carbon Fraction in Above-ground Biomass	I Carbon Released from Decay of Above-ground Biomass (kt C)
STEP 5										
					D = (B-C)	E = (A x D)		G = (E x F)		I = (G x H)
Tropical	Wet/Very Moist									
	Moist, short dry season									
	Moist, long dry season									
	Dry									
	Montane Moist									
	Montane Dry									
Tropical Savanna/Grasslands										
Temperate	Coniferous									
	Broadleaf									
Grasslands										
Boreal	Mixed Broadleaf/ Coniferous									
	Coniferous									
	Forest-tundra									
Grasslands/Tundra										
Other										
									Subtotal	

MODULE	**LAND-USE CHANGE AND FORESTRY**		
SUBMODULE	**FOREST AND GRASSLAND CONVERSION - CO_2 FROM BIOMASS**		
WORKSHEET	**5-2**		
SHEET	**5 OF 5 SUMMARY AND CONVERSION TO CO_2**		
STEP 6			
A Immediate Release From Burning (kt C)	B Delayed Emissions From Decay (kt C) (10-year average)	C Total Annual Carbon Release (kt C)	D Total Annual CO_2 Release (Gg CO_2)
		C = A + B	D = C x (44/12)

MODULE			**LAND-USE CHANGE AND FORESTRY**				
SUBMODULE			**ON-SITE BURNING OF FORESTS - NON-CO_2 TRACE GASES FROM BURNING BIOMASS**				
WORKSHEET			**5-3**				
SHEET			**1 OF 1 NON-CO_2 GAS EMISSIONS**				
STEP 1			**STEP 2**				
A Quantity of Carbon Released (kt C)	B Nitrogen-Carbon Ratio	C Total Nitrogen Released (kt N)		D Trace Gas Emissions Ratios	E Trace Gas Emissions (kt C)	F Conversion Ratio	G Trace Gas Emissions from Burning of Cleared Forests (Gg CH_4, CO)
(From column K, sheet 2 of Worksheet 5-2)		C = (A x B)			E = (A x D)		G = (E x F)
			CH_4			16/12	
			CO			28/12	
					kt N		Gg N_2O, NO_x
					E = (C x D)		G = (E x F)
			N_2O			44/28	
			NO_x			46/14	

MODULE	LAND-USE CHANGE AND FORESTRY	
SUBMODULE	ABANDONMENT OF MANAGED LANDS	
WORKSHEET	5-4	
SHEET	1 OF 3 CARBON UPTAKE BY ABOVEGROUND REGROWTH - FIRST 20 YEARS	

Vegetation types		STEP 1				
		A 20-Year Total Area Abandoned and Regrowing (kha)	B Annual Rate of Aboveground Biomass Growth (t dm/ha)	C Annual Aboveground Biomass Growth (kt dm)	D Carbon Fraction of Aboveground Biomass	E Annual Carbon Uptake in Aboveground Biomass (kt C)
				C = (A x B)		E = (C x D)
Tropical	Wet/Very Moist					
	Moist, short dry season					
	Moist, long dry season					
	Dry					
	Montane Moist					
	Montane Dry					
Tropical Savanna/Grasslands						
Temperate	Coniferous					
	Broadleaf					
Grasslands						
Boreal	Mixed Broadleaf/Coniferous					
	Coniferous					
	Forest tundra					
Grasslands/Tundra						
Other						
					Subtotal	

	MODULE	**LAND-USE CHANGE AND FORESTRY**				
	SUBMODULE	**ABANDONMENT OF MANAGED LANDS**				
	WORKSHEET	**5-4**				
	SHEET	**2 OF 3 CARBON UPTAKE BY ABOVEGROUND REGROWTH - > 20 YEARS**				
		STEP 2				
Vegetation types		G Total Area Abandoned for more than Twenty Years (kha)	H Annual Rate of Aboveground Biomass Growth (t dm/ha)	I Annual Aboveground Biomass Growth (kt dm)	J Carbon Fraction of Above ground Biomass	K Annual Carbon Uptake in Aboveground Biomass (kt C)
				I = (J x H)		K = (I x J)
Tropical	Wet/Very Moist					
	Moist, short dry season					
	Moist, long dry season					
	Dry					
	Montane Moist					
	Montane Dry					
Tropical Savanna/Grasslands						
Temperate	Coniferous					
	Broadleaf					
Grasslands						
Boreal	Mixed Broadleaf/Coniferous					
	Coniferous					
	Forest tundra					
Grasslands/Tundra						
Other						
					Subtotal	

MODULE	**LAND-USE CHANGE AND FORESTRY**
SUBMODULE	**ABANDONMENT OF MANAGED LANDS**
WORKSHEET	**5-4**
SHEET	**3 OF 3 TOTAL CO_2 REMOVALS FROM ABANDONED LANDS**

STEP 3	
L Total Carbon Uptake from Abandoned Lands (kt C)	M Total Carbon Dioxide Uptake (Gg CO_2)
L = (E + K)	M = (L x (44/12))

MODULE		**LAND-USE CHANGE AND FORESTRY**					
SUBMODULE		**CHANGE IN SOIL CARBON FOR MINERAL SOILS**					
WORKSHEET		**5-5**					
SHEET		**1 OF 4**					
STEPS 1 AND 2					**STEP 3**		
A Land-use/ Management Systems	B Soil type	C Soil Carbon (t) (Mg C/ha)	D Land Area (t-20) (Mha)	E Land Area (t) (Mha)	F Soil Carbon (t-20) (Tg)	G Soil Carbon (t) (Tg)	H Net change in Soil Carbon in Mineral Soils (Tg per 20 yr)
					F = (C x D)	G = (C x E)	H = (G - F)
	High activity soils						
	Low activity soils						
	Sandy						
	Volcanic						
	Wetland (Aquic)						
Totals							

Note that land areas in columns D and E, summed over all land-use/management systems used in the inventory should be equal. Total land areas within each soil type, across all land-use systems, should also remain constant over the inventory period.

		MODULE	LAND-USE CHANGE AND FORESTRY			
		SUBMODULE	SOIL CARBON FOR AGRICULTURALLY IMPACTED LANDS			
		WORKSHEET	5-5A (SUPPLEMENTAL)			
		SHEET	1 OF 1			
A Land-use/ Management Systems	B Soil type	C Soil Carbon under Native Vegetation (Mg C/ha)	D Base Factor	E Tillage Factor	F Input Factors	G Soil Carbon in Agriculturally Impacted Lands (Mg C/ha)
						E = (C x D x E x F)
	High Activity Soils					
	Low Activity Soils					
	Sandy					
	Volcanic					
	Wetland (Aquic)					

MODULE	**LAND-USE CHANGE AND FORESTRY**
SUBMODULE	**CARBON EMISSIONS FROM INTENSIVELY-MANAGED ORGANIC SOILS**
WORKSHEET	**5-5**
SHEET	**2 OF 4**

	STEP 4		
Agricultural Use of Organic Soils	A Land Area (ha)	B Annual Loss Rate (MgC/ha/yr) (Default)	C Net Carbon Loss from Organic Soils (Mg/yr)
			C = (A x B)
Cool temperate			
Upland crops			
Pasture/Forest			
Warm temperate			
Upland crops			
Pasture/Forest			
Tropical			
Upland crops			
Pasture/Forest			
		Total	

MODULE	**LAND-USE CHANGE AND FORESTRY**
SUBMODULE	**CARBON EMISSIONS FROM LIMING OF AGRICULTURAL SOILS**
WORKSHEET	**5-5**
SHEET	**3 OF 4**

	STEP 5		
Type of lime	A Total Annual Amount of Lime (Mg)	B Carbon Conversion Factor	C Carbon Emissions from Liming (Mg C)
			C = (A x B)
Limestone $Ca(CO_3)$		0.120	
Dolomite $CaMg(CO_3)_2$		0.122	
		Total	

MODULE	**LAND-USE CHANGE AND FORESTRY**				
SUBMODULE	**CALCULATION OF TOTAL CO_2-C EMISSIONS FROM AGRICULTURALLY-IMPACTED SOILS**				
WORKSHEET	**5-5**				
SHEET	**4 OF 4**				
	STEP 6				
Source	A Worksheet values	B Unit Conversion Factor	C Total Annual Carbon Emissions (Gg)	D Convert to Total Annual CO_2 Emission (Gg/yr)	
			C = (A x B)	D= C x (44/12)	
Total Net Change in Soil Carbon in Mineral Soils		-50			
Total Net Carbon Loss from Organic Soils		0.001			
Carbon Emissions from Liming		0.001			
			Total		