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 native ecosystem types, 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:

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

Worksheet 5-5A (Supplemental): 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 all 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								