MODULE 4
AGRICULTURE

4. AGRICULTURE

4.1 Introduction

The Agriculture module looks at greenhouse gas emissions from five sources:

- Domestic Livestock: Enteric Fermentation and Manure Management
- Rice Cultivation: Flooded Rice Fields
- Prescribed Burning of Savannas
- Field Burning of Agricultural Residues
- Agricultural Soils

4.2 Domestic Livestock

4.2.1 Introduction

This submodule deals with methane and nitrous oxide from two sources:

- enteric fermentation
- manure management

Methane from enteric fermentation is produced in herbivores as a by-product of the digestive process by which carbohydrates are broken down by micro-organisms into simple molecules for absorption into the blood-stream. Both ruminant animals (e.g., cattle, sheep) and some non-ruminant animals (e.g., pigs, horses) produce methane, although ruminants are the largest source. The amount of CH_4 that is released depends upon the type, age and weight of the animal and the quantity and quality of the feed consumed.

Methane from the management of animal manure occurs as the result of its decomposition under anaerobic conditions. These conditions often occur when a large number of animals are managed in a confined area (e.g., dairy farms, beef feedlots, and swine and poultry farms).

Emissions of methane from wild animals and termites are not included in this submodule. The focus in the IPCC *Guidelines* is on anthropogenic emissions. While there are human interactions with natural sources such as wild animals and termites, they are complex and highly uncertain.

4.2.2 Data sources

There are no individual sources that will provide all the data needed to estimate methane emissions from domestic livestock. The Food and Agriculture Organisation (FAO) of the United Nations publishes a series entitled *The FAO Production Yearbook* (e.g., FAO, 1991). This series has information about livestock populations and the production and consumption of livestock products. The FAO data should be supplemented with studies conducted for individual countries. Many countries publish results of their agricultural census that includes data on production levels in addition to livestock populations. Table 4-1 summarises the data needed.

TABLE 4-1
LIVESTOCK POPULATION DATA COLLECTED IN TIER 1 STEP 1

Livestock	Data Collected				
	Population (# head)	Milk Production (kg/head/yr)	Population by Climate (%)		
			Cool	Temperate	Warm
Dairy Cattle	Average Annual Population	Milk Production per Head	% Cool	% Temp.	% Warm
Non-dairy Cattle	Average Annual Population	Not Applicable (NA)	% Cool	% Temp.	% Warm
Buffalo	Average Annual Population	(NA)	% Cool	% Temp.	% Warm
Sheep	Average Annual Population	(NA)	% Cool	% Temp.	% Warm
Goats	Average Annual Population	(NA)	% Cool	% Temp.	% Warm
Camels	Average Annual Population	(NA)	% Cool	% Temp.	% Warm
Horses	Average Annual Population	(NA)	% Cool	% Temp.	% Warm
Mules and Asses	Average Annual Population	(NA)	% Cool	% Temp.	% Warm
Swine	Average Annual Population	(NA)	% Cool	% Temp.	% Warm
Poultry	Average Annual Population	(NA)	% Cool	% Temp.	% Warm

Climate regions are defined in terms of annual average temperature as follows: Cool = less than 15°C; temperate = 15°C to 25°C inclusive; and warm = greater than 25°C.

4.2.3 Methodology

Although the methodological issues are very complex, a simplified methodology is used for the purposes of this *Workbook*.

For a detailed discussion of the methodology, see the *Greenhouse Gas Inventory Reference Manual.* Broadly, emissions are calculated by applying an emission factor to the number of animals of each livestock type in the country to produce a total for enteric fermentation. Default emission factors are provided for developed and developing countries with more regional detail for cattle, the most important source from this activity.

The same basic methodology is used to estimate emissions from manure management. In this area default emission factors are provided by region and for three different climate regimes. Simple multiplication of populations by emission factors produces emissions estimates.

Completing the Worksheet

Use WORKSHEET 4-1 METHANE AND NITROUS OXIDE EMISSIONS FROM DOMESTIC LIVESTOCK ENTERIC FERMENTATION AND MANURE MANAGEMENT at the end of this module to record the data.

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 EMISSIONS FROM ENTERIC FERMENTATION

1 For each type of livestock in the Worksheet, enter the number in thousands in column A.

Refer to FAO Production Yearbooks (e.g., FAO 1991) if there are no locally available data. It is recommended that national experts use three-year averages for activity data if available so that the data not be skewed in the event that the base year of the inventory was an exceptional year not representative of the country's normal activity level.

2 For each type of livestock, enter an average Emission Factor in column B in kilograms per head per year (this is the same as tonnes per thousand head per year). Use a figure from the tables below or more precise locally available data. Because cattle are the most important source and because the emission factors for cattle vary significantly among regions, region-specific default factors are provided. Choose emission factors for cattle that are most appropriate for your national situation.

TABLE 4-2
ENTERIC FERMENTATION METHANE EMISSIONS FACTORS
(KG CH_4 PER HEAD PER YEAR OR T CH_4 PER 1000 HEAD PER YEAR)

Livestock	Developed Countries	Developing Countries
Buffalo	55	55
Sheep	8	5
Goats	5	5
Camels	46	46
Horses	18	18
Mules and Asses	10	10
Swine	1.5	1.0
Poultry	Not estimated	Not estimated

All Estimates are + or - 20%.
See the *Greenhouse Gas Inventory Reference Manual* for sources.

3 Multiply the number of cattle by the Average Emissions Factors to give Emissions from Enteric Fermentation in tonnes per year. Enter the result in column C.

TABLE 4-3
ENTERIC FERMENTATION METHANE EMISSION FACTORS FOR CATTLE

Regional Characteristics	Cattle Type	Emissions Factor (kg CH_4/head/yr)	Comments
North America: Highly productive commercialised dairy sector feeding high quality forage and grain. Separate beef cow herd, primarily grazing with feed supplements seasonally. Fast-growing beef steers/heifers finished in feedlots on grain. Dairy cows are a small part of the population.	Dairy	118	Average milk production of 6700 kg/head/yr
	Non-dairy	47	Includes beef cows, bulls, calves, growing steers/heifers, and feedlot cattle.
Western Europe: Highly productive commercialised dairy sector feeding high quality forage and grain. Dairy cows also used for beef calf production. Very small dedicated beef cow herd. Minor amount of feedlot feeding with grains.	Dairy	100	Average milk production of 4200 kg/head /yr
	Non-dairy	48	Includes bulls, calves, and growing steers/heifers.
Eastern Europe: Commercialised dairy sector feeding mostly forages. Separate beef cow herd, primarily grazing. Minor amount of feedlot feeding with grains.	Dairy	81	Average milk production of 2550 kg/head/yr
	Non-dairy	56	Includes beef cows, bulls, and young.
Oceania: Commercialised dairy sector based on grazing. Separate beef cow herd, primarily grazing range lands of widely varying quality. Growing amount of feedlot feeding with grains. Dairy cows are a small part of the population.	Dairy	68	Average milk production of 1700 kg/head/yr
	Non-dairy	53	Includes beef cows, bulls, and young.
Latin America: Commercialised dairy sector based on grazing. Separate beef cow herd grazing pastures and range lands. Minor amount of feedlot feeding with grains. Growing beef cattle comprise a large portion of the population.	Dairy	57	Average milk production of 800 kg/head/yr
	Non-dairy	49	Includes beef cows, bulls, and young.

TABLE 4-3 (CONTINUED) ENTERIC FERMENTATION METHANE EMISSION FACTORS FOR CATTLE			
Regional Characteristics	Cattle Type	Emissions Factor (kg CH_4/head/yr)	Comments
Asia: Small commercialised dairy sector. Most cattle are multi-purpose, providing draft power and some milk within farming regions. Small grazing population. Cattle of all types are smaller than those found in most other regions.	Dairy Non-dairy	56 44	Average milk production of 1650 kg/head /yr Includes multi-purpose cows, bulls, and young.
Africa and Middle East: Commercialised dairy sector based on grazing with low production per cow. Most cattle are multi-purpose, providing draft power and some milk within farming regions. Some cattle graze over very large areas. Cattle of all types are smaller than those found in most other regions.	Dairy Non-dairy	36 32	Average milk production of 475 kg/head /yr Includes multi-purpose cows, bulls, and young.
Indian Subcontinent: Commercialised dairy sector based on crop by-product feeding with low production per cow. Most bullocks provide draft power and cows provide some milk in farming regions. Small grazing population. Cattle in this region are the smallest compared to cattle found in all other regions.	Dairy Non-dairy	46 25	Average milk production of 900 kg/head /yr Includes cows, bulls, and young. Young comprise a large portion of the population.
See the Greenhouse Gas Inventory Reference Manual for sources.			

STEP 2 ESTIMATING EMISSIONS FROM MANURE MANAGEMENT SYSTEMS

1 For each type of animal, enter the Emissions Factor for Manure Management in column D in kilograms per head per year. Use default data in the tables which follow or more precise locally available data.

Table 4-4 provides default emission factors for most livestock types with different values for developed and developing countries to reflect different conditions and typical practices. Factors are also provided for 3 different climates. Users should select the factors which best represent their conditions. For large countries it may be necessary to subdivide populations into more than one climate region. In that case the user can proceed with calculations in one of two ways.

a Develop an average emissions factor. For example:

If 25 per cent of sheep are in a temperate region and 75 per cent in a warm region, then

EF= (0.25 x 0.16) + (0.75 x 0.21) = 0.20 kg/head/yr

If users do develop and average emission factors, they should state what they have done and should document their sources.

b An alternative approach is to make extra copies of the Worksheet and complete one for each region for the manure portion, then add the results and enter the sum on the main Worksheet.

Swine, buffalo and cattle are the most important source of manure emissions and the most variable by region, therefore detailed emission factors are provided in a separate table.

2 Multiply the Number of Animals by the Emission Factor for Manure Management to give the Emissions from Manure Management in t/yr. Enter the results in column E.

TABLE 4-4
EMISSIONS FACTORS FOR MANURE MANAGEMENT
(KG CH_4 PER HEAD PER YEAR)

Livestock	Developed Countries			Developing Countries		
	Cool	Temp.[a]	Warm	Cool	Temp.[a]	Warm
Sheep	0.19	0.28	0.37	0.10	0.16	0.21
Goats	0.12	0.18	0.23	0.11	0.17	0.22
Camels	1.59	2.38	3.17	1.28	1.92	2.56
Horses	1.39	2.08	2.77	1.09	1.64	2.18
Mules and Asses	0.76	1.14	1.51	0.60	0.90	1.19
Poultry[b]	0.078	0.117	0.157	0.012	0.018	0.023

The range of estimates reflects cool to warm climates. Climate regions are defined in terms of annual average temperature as follows: Cool = less than 15°C; Temperate = 15°C to 25°C inclusive; and Warm = greater than 25°C. Cool, Temperate and Warm regions are estimated using Methane Conversion Factors of 1%, 1.5% and 2%, respectively.

[a] Temp. = Temperate climate region.

[b] Chickens, ducks, and turkeys.

All estimates are ± 20 percent.

Sources: Emission factors developed from: feed intake values and feed digestibilities used to develop the enteric fermentation emission factors (see Appendix A of the *Reference Manual* Chapter 4); MCF, and B_o values reported in Woodbury and Hashimoto (1993). All manure is assumed to be managed in dry systems, which is consistent with the manure management system usage reported in Woodbury and Hashimoto (1993).

TABLE 4-5
MANURE MANAGEMENT EMISSION FACTORS FOR CATTLE, SWINE, AND BUFFALO

Regional Characteristics	Livestock Type	Emissions Factor by Climate Region[a] (kg/head/year)		
		Cool	Temperate	Warm
North America: Liquid-based systems are commonly used for dairy and swine manure. Non-dairy manure is usually managed as a solid and deposited on pastures or ranges.	Dairy Cattle	36	54	76
	Non-dairy Cattle	1	2	3
	Swine	10	14	18
Western Europe: Liquid / slurry and pit storage systems are commonly used for cattle and swine manure. Limited cropland is available for spreading manure.	Dairy Cattle	14	44	81
	Non-dairy Cattle	6	20	38
	Swine	3	10	19
	Buffalo	3	8	17
Eastern Europe: Solid based systems are used for the majority of manure. About one-third of livestock manure is managed in liquid-based systems.	Dairy Cattle	6	19	33
	Non-dairy Cattle	4	13	23
	Swine	4	7	11
	Buffalo	3	9	16
Oceania: Virtually all livestock manure is managed as a solid on pastures and ranges. About half of the swine manure is managed in anaerobic lagoons.	Dairy Cattle	31	32	33
	Non-dairy Cattle	5	6	7
	Swine	20	20	20
Latin America: Almost all livestock manure is managed as a solid on pastures and ranges. Buffalo manure is deposited on pastures and ranges.	Dairy Cattle	0	1	2
	Non-dairy Cattle	1	1	1
	Swine	0	1	2
	Buffalo	1	1	2
Asia: About half of cattle manure is used for fuel with the remainder managed in dry systems. Almost 40% of swine manure is managed as a liquid. Buffalo manure is managed in drylots and deposited in pastures and ranges.	Dairy Cattle	7	16	27
	Non-dairy Cattle	1	1	2
	Swine	1	4	7
	Buffalo	1	2	3
Africa: Almost all livestock manure is managed as a solid on pastures and ranges.	Dairy Cattle	1	1	1
	Non-dairy Cattle	0	1	1
	Swine	0	1	2

TABLE 4-5 (CONTINUED) MANURE MANAGEMENT EMISSION FACTORS FOR CATTLE, SWINE, AND BUFFALO				
Regional Characteristics	Livestock Type	Emissions Factor by Climate Region[a] (kg/head/year)		
		Cool	Temperate	Warm
Middle East: Over two-thirds of cattle manure is deposited on pastures and ranges. About one-third of swine manure is managed in liquid-based systems. Buffalo manure is burned for fuel or managed as a solid.	Dairy Cattle Non-dairy Cattle Swine Buffalo	1 1 1 4	2 1 3 5	2 1 6 5
Indian Subcontinent: About half of cattle and buffalo manure is used for fuel with the remainder managed in dry systems. About one-third of swine manure is managed as a liquid.	Dairy Cattle Non-dairy Cattle Swine Buffalo	5 2 3 4	5 2 4 5	6 2 6 5

[a]Cool climates have an average temperature below 15°C; temperate climates have an average temperature ranging from 15°C to 25°C inclusive; warm climates have an average temperature above 25°C. All climate categories are not necessarily represented within every region. For example, there are no significant warm areas in Eastern or Western Europe. Similarly, there are no significant cool areas in Africa and the Middle East.

Note: Significant buffalo populations do not exist in North America, Oceania, or Africa.

See the *Greenhouse Gas Inventory Reference Manual* for sources.

STEP 3 ESTIMATING METHANE EMISSIONS FROM ENTERIC FERMENTATION AND MANURE MANAGEMENT

1 Sum emissions for Enteric Fermentation and Manure Management and enter the totals at the bottom of the Worksheet.

2 Add the two totals together to give Total Annual Emissions from Domestic Livestock.

3 Divide the final result by 1,000 to express it as gigagrams. Enter the result in column F.

STEP 4 ESTIMATING N_2O EMISSIONS FROM ANIMAL WASTE MANAGEMENT SYSTEMS

EQUATION 1

$$Nex_{(AWMS)} = \Sigma_{(T)}[N_{(T)} \times Nex_{(T)} \times AWMS_{(T)}]$$

Where :

$Nex_{(AWMS)}$ = N excretion per Animal Waste Management System (kg/yr) (see Step 1 in the agricultural soils Section 4.6);

$N_{(T)}$ = number of animals of type T in the country;

$Nex_{(T)}$ = N excretion of animals of type T in the country (kg N/animal /yr) (see Table 4-6);

$AWMS_{(T)}$ = fraction of $Nex_{(T)}$ that is managed in one of the different distinguished animal waste management systems for animals of type T in the country; (see Table 4-7);

T = type of animal category.

Worksheet 4-1 (Supplemental) NITROGEN EXCRETION PER AWMS

Use the Supplemental Worksheet 4-1 to calculate Nitrogen Excretion per Animal Waste Management System (AWMS). Make extra copies of the Worsheet and complete one for each AWMS.

1 Enter the Number of Animals, N, in a country in column A.

2 Enter the Nitrogen Excretion, Nex, for each animal type in column B. Default data are provided in Table 4-6.

3 Enter the Fraction of Manure Nitrogen per AWMS in column C. Default data are provided in Table 4-7.

4 Multiply columns A, B, and C, and enter the results into column D.

5 Sum the values in column D and enter the total in the bottom of the column to obtain the Nitrogen Excretion for each AWMS, $Nex_{(AWMS)}$, in kilograms per year.

EQUATION 2

$$N_2O_{(AWMS)} = \Sigma[\ Nex_{(AWMS)} \times EF_{3(AWMS)}]$$

where:

$N_2O_{(AWMS)}$ = N_2O emissions from all Animal Waste Management Systems in the country (kg N/yr);

$Nex_{(AWMS)}$ = See Equation 1, above;

$EF_{3(AWMS)}$ = N_2O emission factor for an AWMS (kg N_2O-N/kg of Nex in AWMS); (see Table 4-8).

Use Worksheet 4-1, Sheet 2 of 2 to calculate N_2O Emissions from all Animal Waste Management Systems.

NITROUS OXIDE FROM AWMS

Nitrogen Excretion Nex from all AWMS are estimated here. However, note that N_2O emissions from anaerobic lagoons, liquid systems, solid storage and drylot, and "other systems" are reported in this section while daily spread and pasture range and paddock are reported under Agricultural Soils (see Section 4.6).

1 Enter the values of Nitrogen Excretion $Nex_{(AWMS)}$ from the bottom of column D of each Supplemental Worksheet into the corresponding Animal Waste Management System in column A.

2 For each type of Animal Waste Management System, enter Emission Factor for Animal Waste Management Systems in column B. Use default values provided in Table 4-8 or more precise locally available data.

3 Multiply the value of N excretion (column A) by the N_2O Emission Factor for Animal Waste Management System (column B) and then by the conversion ratio 44/28 to give the Total Annual Emissions of N_2O. Multiply the final result by 10^{-6} to express it as gigagrams. Enter the results in column C.

4 Sum the values in column C and enter the result in the bottom of the column.

TABLE 4-6
TENTATIVE DEFAULT VALUES FOR NITROGEN EXCRETION PER HEAD OF ANIMAL PER REGION (kg/animal/yr)[a]

Region	Type of Animal					
	Non-dairy cattle	Dairy cattle	Poultry	Sheep	Swine	Others
North America	70	100	0.6	16	20	25
Western Europe	70	100	0.6	20	20	25
Eastern Europe	50	70	0.6	16	20	25
Oceania	60	80	0.6	20	16	25
Latin America	40	70	0.6	12	16	40
Africa	40	60	0.6	12	16	40
Near East & Mediterranean	50	70	0.6	12	16	40
Asia & Far East	40	60	0.6	12	16	40

[a] *Source:* Ecetoc (1994), Vetter et al. (1988), Steffens and Vetter (1990).

TABLE 4-7
DEFAULT VALUES FOR PERCENTAGE OF MANURE N PRODUCED IN DIFFERENT ANIMAL WASTE MANAGEMENT SYSTEMS IN DIFFERENT WORLD REGIONS (FROM SAFLEY ET AL., 1992)

Region	Type of Animal	Percentage of Manure Production per Animal Waste Management Systems						
		Anaerobic Lagoon	Liquid System	Daily Spread	Solid Storage and Drylot	Pasture Range and Paddock	Used Fuel	Other System
North America	Non-dairy Cattle (D)	0	1	0	14	84	0	1
	Dairy Cattle	10	23	37	23	0	0	7
	Poultry (E)	5	4	0	0	1	0	90
	Sheep	0	0	0	2	88	0	10
	Swine	25	50	0	18	0	0	6
	Other animals (F)	0	0	0	0	92	0	8
Western Europe	Non-dairy Cattle (D)	0	55	0	2	33	0	9
	Dairy Cattle	0	46	24	21	8	0	1
	Poultry (E)	0	13	0	1	2	0	84
	Sheep	0	0	0	2	87	0	11
	Swine	0	77	0	23	0	0	0
	Other animals (F)	0	0	0	0	96	0	4
Eastern Europe	Non-dairy Cattle (D)	8	39	0	52	0	0	1
	Dairy Cattle	0	18	1	67	13	0	0
	Poultry (E)	0	28	0	0	1	0	71
	Sheep	0	0	0	0	73	0	27
	Swine	0	29	0	0	27	0	45
	Other animals (F)	0	0	0	0	92	0	8

TABLE 4-7 (CONTINUED)
DEFAULT VALUES FOR PERCENTAGE OF MANURE N PRODUCED IN DIFFERENT ANIMA L WASTE MANAGEMENT SYSTEMS IN DIFFERENT WORLD REGIONS
(FROM SAFLEY ET AL., 1992)

Region	Type of Animal	Percentage of Manure Production per Animal Waste Management Systems						
		Anaerobic Lagoon	Liquid System	Daily Spread	Solid Storage and Drylot	Pasture Range and Paddock	Used Fuel	Other System
Oceania	Non-dairy Cattle (D)	0	0	0	0	100	0	0
	Dairy Cattle	0	0	0	0	100	0	0
	Poultry (E)	0	0	0	0	3	0	97
	Sheep	0	0	0	0	100	0	0
	Swine	55	0	0	17	0	0	28
	Other animals (F)	0	0	0	0	100	0	0
Latin America	Non-dairy Cattle (D)	0	0	0	0	99	0	1
	Dairy Cattle	0	1	62	1	36	0	0
	Poultry (E)	0	9	0	0	42	0	49
	Sheep	0	0	0	0	100	0	0
	Swine	0	8	2	51	0	0	40
	Other animals (F)	0	0	0	0	99	0	1
Africa	Non-dairy Cattle (D)	0	0	1	3	96	0	0
	Dairy Cattle	0	0	12	0	83	0	5
	Poultry (E)	0	0	0	0	81	0	19
	Sheep	0	0	0	1	99	0	1
	Swine	0	7	0	93	0	0	0
	Other animals (F)	1	0	0	0	99	0	1

TABLE 4-7 (CONTINUED)
DEFAULT VALUES FOR PERCENTAGE OF MANURE N PRODUCED IN DIFFERENT ANIMAL WASTE MANAGEMENT SYSTEMS IN DIFFERENT WORLD REGIONS (FROM SAFLEY ET AL., 1992)

		Per centage of Manure Production per Animal Waste Management Systems						
Region	Type of Animal	Anaerobic Lagoon	Liquid System	Daily Spread	Solid Storage and Drylot	Pasture Range and Paddock	Used Fuel	Other System
Near East and Mediterranean	Non-dairy Cattle (D)	0	0	2	0	77	18	2
	Dairy Cattle	0	0	3	3	77	18	0
	Poultry (E)	0	1	0	0	71	0	28
	Sheep	0	0	0	0	100	0	0
	Swine	0	32	0	68	0	0	0
	Other animals (F)	0	0	0	0	100	0	0
Asia and Far East	Non-dairy Cattle (D)	0	0	16	14	29	40	0
	Dairy Cattle	6	4	21	0	24	46	0
	Poultry (E)	1	2	0	0	44	1	52
	Sheep	0	0	0	0	83	0	17
	Swine	1	38	1	53	0	7	0
	Other animals (F)	0	0	0	0	95	0	5

(D) Includes buffalo
(E) Includes chickens, turkeys and ducks
(F) Includes goats, horses, mules, donkeys and camels

TABLE 4-8 TENTATIVE DEFAULT VALUES FOR N_2O EMISSION FACTORS FROM ANIMAL WASTE PER ANIMAL WASTE MANAGEMENT SYSTEM (KG N_2O–N/KG NITROGEN EXCRETED)	
Animal Waste Management System[a]	Emission Factor EF_3
Anaerobic lagoons[b]	0.001 (<0.002)
Liquid systems[b]	0.001 (<0.001)
Daily spread[c]	0.0 (no range)
Solid storage and drylot[c]	0.02 (0.005-0.03)
Pasture range and paddock (grazing)[d]	0.02 (0.005-0.03)
Used as fuel[e]	Not included in this Chapter
Other systems[b]	0.005

[a] The fraction of manure nitrogen produced in different Animal Waste Management Systems for cattle, swine and buffalo can be estimated as proposed in Table 4-7, or as given by Safley et al. (1992).

[b] To be reported under "Manure Management".

[c] To be reported under "Agricultural Soils" (Section 4.6) under direct soil emissions from agricultural fields after spreading. (Emissions are assumed not to occur before spreading).

[d] To be reported under "Agricultural Soils" (Section 4.6) under direct soil emissions from animal production.

[e] To be reported in the Energy Chapter.

4.3 Rice Cultivation

4.3.1 Introduction

Anaerobic decomposition of organic material in flooded rice fields produces methane (CH_4), which escapes to the atmosphere primarily by diffusive transport through the rice plants during the growing season. Upland rice fields, which are not flooded and therefore do not produce significant quantities of CH_4, account for approximately 10 per cent of the global rice production and about 15 per cent of the global rice area under cultivation. The remaining area is grown for wetland rice, consisting of irrigated, rainfed, and deepwater rice. The global wetland rice area harvested annually in the early 1980s was about 123.2 million hectares (total harvested area including upland rice is 144 Mha), over 90 per cent of which was in Asia (Neue *et al.,* 1990).[1]

The measurements at various locations of the world show that there are large temporal variations of CH_4 fluxes and that the flux differs markedly with soil type and texture, application of organic matter and mineral fertiliser (Neue and Sass, 1994). The wide variations in CH_4 fluxes also

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[1] The term "harvested area" has a different meaning from "cultivated area" in that the former accounts for double and triple cropping. For example, if a country has 10 million hectares of land under rice cultivation, all of which are double-cropped (i.e., two crops of rice are grown on each hectare each year), then this country has 20 million hectares of rice area harvested annually.

indicate that the flux is critically dependent upon several factors including climate, characteristics of soils and paddy, and agricultural practices, particularly water regime. The parameters that affect methane emissions vary widely both spatially and temporally. Multiple year data sets near the same location and under similar conditions can lead to substantial differences in seasonal methane emission levels, making it difficult to establish a single number as the methane emission level from a field, let alone at a regional or country level. Thus, at the current level of understanding, a reported range in methane emission levels for a country is more realistic than a single number.

4.3.2 Data sources

Area Statistics

Table 4-9 contains information on harvested area of rice according to statistics from the FAO Yearbook (UN, 1992), China Agricultural Yearbook (1990), IRRI RICE Almanac (IRRI, 1994) and World Rice Statistics (IRRI, 1993). Allocation of areas to categories, e.g., irrigated, rainfed (flood prone and lowland rainfed) and upland rice for main rice-producing countries were based on the IRRI Rice Almanac (IRRI, 1994) and for other rice-producing countries these categories were based on IRRI (1990), Huke (1982) and Grist (1986). Actual percentage of the irrigated, rainfed, and flood prone areas which are continuously flooded or have an aeration period greater than 3 days or multiple aerations, are to be obtained from the country specific data.

ESTIMATING HARVESTED AREA

The annual harvested area cultivated under these conditions is given by the cultivated area (in m2/yr) times the number of cropping seasons per year. If some areas are double cropped, they would be counted twice as the harvested area.

Seasonally Integrated flux values

Tables 4-10 and 4-11 provides default emission factors, EF, for various categories of water regimes and multiplication factors for organic amendments. Emissions from upland rice are assumed to be 0 and ignored in the emission calculations.

See the *Reference Manual* for a more detailed discussion of available data sources.

4.3.3 Methodology

Emissions of methane from rice fields can be represented as follows:

EQUATION 1

$$F_C = EF \times A \times 10^{-12}$$

where:

F_C = estimated annual emission of methane from a particular rice water regime and for a given organic amendment, in Tg /yr;

EF = methane emission factor integrated over integrated cropping season, in g/m^2;

A = annual harvested area cultivated under conditions specified above. It is given by the cultivated area times the number of cropping seasons per year, i.e., in m^2/yr.

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.

> **REFLECTING MORE DETAIL**
>
> If you have the necessary data, you can sub-divide your data further to account for different fertilising practices. Furthermore, if regional variations in temperature, cultivation practices, etc. justify it, calculations can be done at sub-national regional level. In either case you should use extra copies of the Worksheet and label them clearly by subcategory or region. You should then aggregate the results to provide a national summary table from the basic categories described in the method.

Use WORKSHEET 4-2 METHANE EMISSIONS FROM FLOODED RICE FIELDS at the end of this module to enter your data. Table 4-9 gives default data for the distribution of rice growing areas and water management types throughout the world.

ESTIMATING METHANE EMISSIONS BY WATER MANAGEMENT REGIME

1 Enter the Harvested Area by water management regime (in square metres x 10^{-9}) in column A.

The annual harvested area cultivated under these conditions is given by the cultivated area (in m^2/yr) times the number of cropping seasons per year. Area cultivated under upland (or dry conditions) is excluded from methane calculations. Table 4-9 provides some default information which can be used if data are not locally available. Note that the data for area harvested provided in Table 4-9 are expressed in units of thousands of hectares. If these data are used they must first be converted to square metres (1000h = 10^7 sq.m).

2 Enter the Scaling Factor for Methane Emissions in column B. Default factors are given for rice ecosystems relative to continuously flooded fields, without organic amendments. Values are provided in Table 4-10 and can be used if more detailed data are not locally available.

3 For conversion to soils with organic amendment, enter a Correction Factor for Organic Amendment in column C. The default value is 2. For soils without organic amendment, correction is not necessary. In this case, enter 1 in column C.

4 Enter the Seasonally Integrated Methane Emission Factor for Continuously Flooded Rice without Organic Amendment (in g/m^2) in column D. Some country specific data are given in Table 4-11. The arithmetic mean of the dataset can be used as a default value, if no other information is available.

5 For each category, multiply the Harvested Area (column A) by the Scaling Factor for Methane Emissions (column B), the Correction Factor for Organic Amendment (column C), and the Seasonally Integrated Methane Emission Factor for Continuously Flooded Rice without Organic Fertilisers (column D). This gives CH_4 Emissions in gigagrams for each rice category. Enter the result in column E.

6 Sum emissions and enter the total at the bottom of column E.

TABLE 4-9
DEFAULT ACTIVITY DATA - HARVESTED RICE

Country or Region	1990 Area (1000s ha)	Irrigated[a] (%)	Upland Rice (%)	Rainfed[b] (%)
Americas				
USA	1114	100	0	0
Belize	2	10	90	0
Costa Rica	53	10	90	0
Cuba	150	100	0	0
Dominican Rep	93	98	2	0
El Salvador	15	10	90	0
Guatemala	15	10	90	0
Haiti	52	40	60	0
Honduras	19	10	90	0
Jamaica	0	40	60	0
Mexico	123	41	59	0
Nicaragua	48	10	90	0
Panama	92	5	95	0
Puerto Rico	0	75	25	0
Trinidad & Tobago	5	45	55	0
Argentina	103	100	0	0
Bolivia	110	25	75	0
Brazil	3945	19	75	6 (0 + 6)
Chile	35	79		0
Columbia	435	67	23	10 (0 + 10)
Ecuador	266	40	10	50
Guyana	68	95	5	0
Paraguay	34	50	50	0
Peru	185	84	16	0
Surinam	58	100	0	0
Uruguay	108	100	0	0
Venezuela	119	90	21	0

TABLE 4.9 (CONT.) DEFAULT ACTIVITY DATA - HARVESTED RICE				
Country or Region	1990 Area (1000s ha)	Irrigated[a] (%)	Upland Rice (%)	Rainfed[b] (%)
Asia				
Brunei	1	79	21	0
Hong Kong	0	100	0	0
Syria	0	100	0	0
Turkey	52	100	0	0
India	42321	53 (16 + 37)	15	32 (16 + 16)
Pakistan	2113	100	0	0
Bangladesh	10435	22	8	70 (23 + 47)
Myanmar	4760	18	6	76 (24 + 52)
Nepal	1445	23	3	74 (8 + 66)
Afghanistan	173	100	0	0
Bhutan	25	50	4	46 (42 + 4)
China [3]	33265	93	2	5 (0 + 5)
Indonesia	10502	72 (22 + 50)	11	17 (10 + 7)
Iran	570	100	0	0
Iraq	78	100	0	0
Japan	2074	99 (2 + 97)	1	0
Malaysia	639	66	12	22 (1 + 21)
Philippines	3319	61	2	37 (2 + 35)
Sri Lanka	828	37	7	56 (3 + 53)
Taiwan	700	97	3	0
Thailand	9650	7	1	92 (7 + 85)
Kampuchea	1800	8	2	90 (42 + 48)
Laos	638	2	37	61 (0 + 61)
Vietnam	6028	53	8	39 (11 + 28)
Democratic Republic of Korea	670	67	13	20
Republic of Korea	1242	100 (9 + 91)	0	0

TABLE 4.9 (CONT.) DEFAULT ACTIVITY DATA - HARVESTED RICE				
Country or Region	1990 Area (1000s ha)	Irrigated[a] (%)	Upland Rice (%)	Rainfed[b] (%)
Europe				
Albania	2	100	0	0
Bulgaria	11	100	0	0
France	20	100	0	0
Greece	15	100	0	0
Hungary	11	100	0	0
Italy	208	100	0	0
Portugal	33	100	0	0
Romania	37	100	0	0
Spain	81	100	0	0
Former USSR	624	100	0	0
Former Yugoslavia	8	100	0	0
PACIFIC				
Australia	102	100	0	0
Fiji	13	50	50	0
Africa				
Algeria	1	100	0	0
Angola	18	100	0	0
Benin	7	10	90	0
Burkina Faso	19	89	11	0
Burundi	12	25	75	0
Cameroon	15	25	75	0
C African Rep	10	25	75	0
Chad	39	25	75	0
Comoros	13	100	0	0
Congo	4	25	75	0
Egypt	436	100	0	0
Gabon	0	25	75	0
Gambia	14	90	10	0

TABLE 4.9 (CONT.) DEFAULT ACTIVITY DATA - HARVESTED RICE				
Country or Region	1990 Area (1000s ha)	Irrigated[a] (%)	Upland Rice (%)	Rainfed[b] (%)
Ghana	85	24	76	0
Guinea Bissau	57	25	75	0
Guinea	608	8	47	45
Ivory Coast	583	6	87	7
Kenya	15	25	75	0
Liberia	168	0	94	6
Madagascar	1160	10	14	76 (2 + 74)
Malawi	29	25	75	0
Mali	222	25	75	0
Mauritania	14	100	0	0
Morocco	6	100	0	0
Mozambique	109	25	75	0
Niger	29	35	65	0
Nigeria	1567	16	51	33 (33 + 0)
Rwanda	3	25	75	0
Senegal	73	25	75	0
Sierra Leone	339	1	67	32
Somalia	5	50	50	0
South Africa	1	100	0	0
Sudan	1	50	50	0
Swaziland	0	25	75	0
Tanzania	375	3	22	75 (0 + 75)
Togo	21	4	96	0
Uganda	37	25	75	0
Zaire	393	5	90	5
Zambia	11	25	75	0
Zimbabwe	0	25	75	0

a Numbers in brackets indicate continuously flooded and intermittently flooded respectively.

b Numbers in brackets indicate continuously flood-prone and drought-prone respectively.

c Values are currently being updated.

Notes: Areas were taken from FAO Yearbook (UN, 1992), China Agricultural Yearbook (1990), World Rice Statistics (IRRI, 1990) and IRRI Rice Almanac 1993-1995 (IRRI, 1993).

TABLE 4-10
SCALING FACTORS FOR METHANE EMISSIONS FOR RICE ECOSYSTEMS RELATIVE TO CONTINUOUSLY FLOODED FIELDS (WITHOUT ORGANIC AMENDMENTS)

Category	Sub-Category[a]			Scaling Factors (relative to emission factors for continuously flooded fields)
Upland	None			0
Lowland	Irrigated	Continuously flooded		1.0
		Intermittently flooded[b]	Single aeration	0.5 (0.2-0.7)
			Multiple aeration	0.2 (0.1-0.3)
	Rainfed	Flood prone		0.8 (0.5-1.0)
		Drought prone		0.4 (0-0.5)
	Deep water	Water depth 50-100 cm		0.8 (0.6-1.0)
		Water depth > 100 cm		0.6 (0.5-0.8)

[a] other rice ecosystem categories, like swamps, inland saline or tidal wetlands may be discriminated within each sub-category according to local emission measurements.

[b] defined as > 3 days aeration during the vegetative period.

Note**:** For irrigated and continuously flooded, lowland rice ecosystems, the default seasonally integrated methane emission is 20 g/m^2 (see Table 4-11) for soils 'without organic amendments'. For conversion to methane emissions from soils 'with organic amendments', apply a default correction factor of 2 (Range 2-5) to the corresponding rice ecosystem for the 'without organic amendment' category.

TABLE 4-11
SEASONALLY INTEGRATED METHANE EMISSION FACTORS FOR CONTINUOUSLY FLOODED RICE WITHOUT ORGANIC FERTILISER IN VARIOUS LOCATIONS OF THE WORLD

Country	Seasonally Integrated Emission Factor, EF[a] (g/m^2)	Literature/Remarks
Australia	22.5	NGGIC, 1996
China	13 (10-22)	Wassman et al., 1993a
India	10 (5 - 15)	Mitra et al., 1996 Parashar et al., 1996
Indonesia	18 (5 - 44)	Nugroho et al., 1994a,b
Italy	36 (17-54)	Schütz et al., 1989a
Japan	15	Minami, 1995
Republic of Korea	15	Shin et al., 1995
Philippines	(25 - 30)	Neue et al., 1994; Wassman et al., 1994
Thailand	16 (4 - 40)	Towpryaoon et al., 1993
USA (Texas)	25 (15 - 35)	Sass and Fisher, 1995
Arithmetic Mean[b]	20 (12-28)	-

[a] It is recognised that the emission factors presented in Table 4-11 will need to be periodically updated as better data become available. However, this dataset represents the best available information at the time of compilation.

[b] The arithmetic mean of the seasonally integrated emission factor, EF, is derived from the values shown in Table 4-11. The range of emission factors is defined as the standard deviation about the mean.

4.4 Prescribed Burning of Savannas

4.4.1 Introduction

Savannas are tropical and subtropical formations with continuous grass coverage. The growth of savannas is controlled by alternating wet and dry seasons: most of the growth occurs during the wet season. Man-made and/or natural fires frequently occur during the dry season, resulting in nutrient recycling and regrowth. Large scale burning takes place primarily in the humid savannas because the arid savannas lack sufficient grass cover to sustain fire. Savannas are burned every one to four years on average, with the highest frequency in the humid savannas of Africa.

The burning of savannas results in instantaneous emissions of carbon dioxide. However, because the vegetation regrows between the burning cycles, the carbon dioxide released to the atmosphere is reabsorbed during the next vegetation growth period. Therefore, this *Workbook* assumes that CO_2 net emissions are zero.

The burning of savannas also releases gases other than CO_2, including methane, carbon monoxide, nitrous oxide and oxides of nitrogen. Unlike CO_2 emissions these are net anthropogenic emissions and should be accounted for.

DEGRADED SAVANNAS

Although the default assumption is that biomass burned on savannas regrows in a short period, this may not always be the case. Sometimes savannas are burned too often, or for other reasons fail to recover completely. Over time savannas can degrade significantly as a result of human intervention. In this case there will be a long-term loss of carbon in aboveground biomass and soils. If this is occurring, the annual carbon loss should be accounted for, if possible, in addition to the information requested in the *Workbook.*

4.4.2 Data sources

There are no routinely published data on the amount of savanna burned, but several assessment papers have been published. The *FAO Forest Resource Assessment 1990: Tropical Countries* (FAO 1993) provides country estimates of savanna (grassland) area and the *Greenhouse Gas Inventory Reference Manual* provides additional references.

4.4.3 Methodology

The non-CO_2 trace gas emissions from savanna burning may be estimated through a series of simple calculations using either locally available data or defaults provided in the tables in this *Workbook*.

First the quantity of biomass that actually burns is calculated by multiplying area of savanna burned by average biomass density and by the fraction of exposed biomass which actually burns.

Second, carbon released is calculated multiplying quantity of biomass burned by fraction oxidised and then by carbon fraction.

The second calculation can be greatly improved by first dividing the quantity of biomass burned into living and dead fractions. The calculation is then carried out for each of these fractions using different fractions oxidised and carbon contents for the living and dead fractions.

NON-METHANE VOLATILE ORGANIC COMPOUNDS

NMVOCs are emitted in significant quantities from biomass burning. These emissions should be estimated using the same approach provided for other non-CO_2 gases. However, the default information has not yet been developed to include this class of gases in the *Workbook.* This is an area to be considered in future improvements to the *Guidelines.*

FRACTIONS

In order to determine the amount of savanna biomass that actually oxidises to release carbon to the atmosphere, several *fractions* must be applied sequentially. To start with, the quantity of biomass exposed to fire is calculated by multiplying the area of savanna burned in the inventory year by the average biomass density (in tonnes of dry matter per hectare). The fractions are then applied as follows.

Fraction which Actually Burns

Under normal open burning conditions all biomass in each hectare does not actually burn. The *Fraction which Actually Burns* (generally 0.80 - 0.85 but may be higher in very dry regions) is applied to derive the kilotonnes of dry matter which actually burn.

Fraction Oxidised

This next fraction to be applied expresses the biomass that oxidises. Not all of the burning biomass oxidises - a small fraction may remain as charcoal. The fraction oxidised is usually 0.8 to 1.0.

Carbon Fraction

The last fraction to be applied determines the amount of carbon that is released from the fraction of biomass which has oxidised.

Third, several ratios are applied to total carbon released to derive estimates of non-CO_2 trace gas emissions, as follows:

- a nitrogen-carbon ratio is applied to estimate total nitrogen content
- ratios for CH_4 and CO as fractions of total carbon
- ratios of N_2O and NO_x as fractions of total nitrogen

The resulting estimates of emissions are converted to total weight (i.e., from CH_4 as C to CH_4 total) using standard factors.

One country may possess more than one type of savanna with different characteristics; burns may vary in efficiency; and burns may take place at different times during the dry season, causing the burning to vary with the state of the vegetation (such as the moisture content and whether the biomass is alive or dead).

If data are locally available savanna burned should be subdivided into relevant subcategories reflecting these variations and entered into the worksheet. If you are relying on the default values in this *Workbook* you will only be able to carry out calculations at a national level.

Completing the Worksheet

STEP 1 ESTIMATING TOTAL BIOMASS THAT ACTUALLY BURNS

Use WORKSHEET 4-3 PRESCRIBED BURNING OF SAVANNAS at the end of this module to record inventory data. You should do this for a single national average category or subdivide if data are locally available for each relevant subcategory of savanna.

1 For each category of savanna, enter the Area Burned (in kilohectares) in column A.

If possible use locally available data for hectares of savanna burned annually. If this is not possible, a crude default approach is to determine the total savanna area and multiply by typical regional defaults for percentage burned annually from Table 4-12 (below).

TABLE 4-12
REGIONAL SAVANNA STATISTICS

Region	Fraction of Total Savanna Burned Annually	Aboveground Biomass Density (t dm/ha)	Fraction of Biomass Actually Burned	Fraction of Aboveground Biomass that is Living
Tropical America	0.50	6.6 ±1.8		
Tropical Asia	0.50	4.9		
Tropical Africa	0.75	6.6 ±1.6		
Sahel zone	0.05-0.15	0.5-2.5*	0.95	0.20
North Sudan zone	0.25-0.50	2-4*	0.85	0.45
South Sudan zone	0.25-0.50	3-6*	0.85	0.45
Guinea zone	0.60-0.80	4-8*	0.90-1.0	0.55
Australia	0.05-0.70	2.1-6		

Regional defaults are for seasonal average densities which should be used for emissions calculations. Values marked with * are maximum, season end densities which are appropriate defaults for these very dry sub-regions.

Note: These are ecological zones that do not correspond directly to areas with political boundaries of the same name. For example, the North and South Sudan Zones include countries other than Sudan and run East-West across the African continent.

See the *Greenhouse Gas Inventory Reference Manual* for sources of these figures.

2 For each category of savanna, enter the Biomass Density of the Savanna (in tonnes of dry matter per hectare) in column B. Table 4-12 provides available summary information by region which can be used as default data.

3 Multiply the Area Burned by the Biomass Density of the Savanna to give the Total Biomass Exposed to Burning (in gigagrams of dry matter, which is the same as kilotonnes dm). Enter the result in column C.

4 Enter the Fraction of Biomass Actually Burned in column D.

Use locally available data if available. You can use a general default figure in the range 0.80 - 0.85. Some specific values for African sub-regions are given in Table 4-12.

5 Multiply Total Biomass Exposed to Burning (column C) by the Fraction Actually Burned (column D) to give the Quantity Actually Burned. Enter the results in column E.

CATEGORIES OF SAVANNAS

A number of users of the draft *Guidelines,* particularly in Africa, have suggested that savannas should be divided into woody savannas and grasslands if possible. For woody savannas, the aboveground biomass densities prior to burning would be higher and the fraction oxidised should be lower, as much of the standing woody biomass would not be burned. Other subcategories by region, time of burning, etc. may also be useful.

STEP 2 ESTIMATING THE PROPORTIONS OF LIVING AND DEAD BIOMASS

1 Enter the Fraction of Living Biomass burned in column F.

Some default figures are in Table 4-12 for specific sub-regions in Africa. In other regions users must provide these values. If no information is available, users can do the calculation using "combined values" (see margin box: categories of savannas).

2 Multiply the Quantity Actually Burned by the Fraction of Biomass Living to give the quantity of Living Biomass Burned (in gigagrams of dry matter). Enter the result in column G.

3 Subtract the Living Biomass Burned from the Quantity of Biomass Actually Burned to give the quantity of Dead Biomass Burned (in gigagrams of dry matter). Enter the result in column H.

STEP 3 ESTIMATING THE TOTAL CARBON RELEASED

COMBINED VALUES

From this point on in the worksheet, each original category is split into two parts - living and dead - for which calculations are made separately. Each row in the worksheet splits into living and dead rows for columns I through J. If users are not able to report living and dead fractions, the default calculation can be done using "combined" values from Table 4-13.

1 For each category of savanna, enter the Fraction Oxidised for *living* and *dead* biomass. Enter the results in the appropriate boxes in column I. Default figures are in Table 4-13.

TABLE 4-13
GENERAL DEFAULT VALUES

	Fraction Oxidised	Carbon Fraction
Living Fraction	0.80	0.45
Dead Fraction	1.0	0.40
Combined	0.90	0.45

2 For each category of savanna multiply the Living Biomass Burned by the Fraction Oxidised for living biomass. **Also,** multiply Dead Biomass Burned by the Fraction Oxidised for dead biomass. Enter the results, in gigagrams of dry matter, in the appropriate boxes in column J.

3 For each category of savanna, living and dead, enter the Carbon Fraction (of dry matter) of living and dead biomass in column K. Default figures are in Table 4-13.

4 Multiply the Total Biomass Burned by the Carbon Fraction for each category of savanna, living and dead, to give the Total Carbon Released. Enter the results in column L in gigagrams of carbon.

5 Add the totals in column L and enter the result in the Total box at the bottom of the column. Carry the result forward to column L at the start of sheet 3 on the next page.

STEP 4 ESTIMATING NON-CO_2 TRACE GAS EMISSIONS FROM SAVANNA BURNING

1 Enter the Nitrogen-Carbon Ratio in column M.

If no data specific to biomass type are locally available, use the general default value for savannas, which is 0.006.

2 Multiply Total Carbon Released (column L) by the Nitrogen-Carbon Ratio to give the Total Nitrogen Content (in gigagrams of Nitrogen). Enter the result in the appropriate box in column N.

3 For each gas - methane (CH_4), carbon monoxide (CO), nitrous oxide (N_2O) and nitrogen oxides (NO_x) - enter an Emission Ratio in column O.

Table 4-14 shows the default ratios.

TABLE 4-14
EMISSION RATIOS AND RANGES FOR SAVANNA BURNING CALCULATIONS

Compound	Default value	Range
CH_4	0.004	0.002 - 0.006
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 the nitrogen compounds are expressed as the ratios of mass of nitrogen compounds released relative to the total mass of nitrogen released from the fuel.
See the *Greenhouse Gas Inventory Reference Manual* for sources.

4 Multiply Total Carbon Released (column L) (for CH_4 and CO), or Total Nitrogen Content (column N) (for N_2O and NO_x) by the emissions ratios in column O to give the total emissions for each gas. Enter the results in column P.

STEP 5 CONVERT EMISSIONS OF CARBON AND NITROGEN INTO METHANE, CARBON MONOXIDE, NITROUS OXIDE AND NITROGEN OXIDE EMISSIONS.

1 Multiply the emissions of each gas expressed as C or N by the appropriate Conversion Ratio[2] in column Q to give the Emissions from Savanna Burning for each gas emitted. Enter the results in column R.

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[2] The molecular weight ratios given above for the emitted gases are with respect to the weight of nitrogen or 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.

4.5 Field Burning of Agricultural Residues

4.5.1 Introduction

Large quantities of agricultural residues are produced from farming systems world-wide. Burning of crop residues in the fields is a common agricultural practice, particularly in developing countries. It has been estimated that as much as 40 per cent of the residues produced in developing countries may be burned in fields, while the percentage is lower in developed countries. It is important to note that some crop residues are removed from the fields and burned as a source of energy, especially in developing countries. Emissions from this type of burning are calculated in the Energy module of this *Workbook*. Users should ensure that residue burning is properly allocated to these two components and not double counted.

This submodule deals exclusively with emissions of methane, carbon monoxide, nitrous oxide and nitrogen oxides from crop residues. In this *Workbook*, field burning of crop residues is not treated as a net source of carbon dioxide because it is assumed that the carbon released to the atmosphere is reabsorbed during the next growing season. However crop residue burning is a significant net source of emissions of methane, carbon monoxide, nitrous oxide and nitrogen oxides.

4.5.2 Data sources

Annual crop production statistics by country for most of the crops from which residues are burned may be found in FAO Production Year Books (e.g., FAO, 1991). Crop specific data for each country on ratios of residue to crop production, fraction of residue burned, dry matter content of residue and carbon and nitrogen contents of residue should be provided by individual countries if available. Table 4-15 *Selected Crop Residue Statistics* shows default data for crop residues.

TABLE 4-15 SELECTED CROP RESIDUE STATISTICS				
Product	Residue / Crop Ratio	Dry Matter Fraction	Carbon Fraction	Nitrogen-Carbon Ratio
Wheat	1.3	0.78-0.88	0.4853	0.012
Barley	1.2	0.78-0.88	0.4567	
Maize	1	0.30-0.50	0.4709	0.02
Oats	1.3			
Rye	1.6			
Rice	1.4	0.78-0.88	0.4144	0.014
Millet	1.4			0.016
Sorghum	1.4			0.02
Pea	1.5			
Bean	2.1			
Soya	2.1			0.05
Potatoes	0.4	0.30-0.60	0.4226	
Feedbeet	0.3	0.10-0.20[a]	0.4072[a]	
Sugarbeet	0.2	0.10-0.20[a]	0.4072[a]	
Jerusalem artichoke	0.8			
Peanut	1			

Note: Crop statistics in this table are not complete. For values not specified you should use values for the most similar crop type as defaults.

See the *Greenhouse Gas Inventory Reference Manual* for sources.

[a] These statistics are for beet leaves.

Completing the Worksheet

STEP 1 CALCULATING THE AMOUNT OF RESIDUE

Use WORKSHEET 4-4 FIELD BURNING OF AGRICULTURAL RESIDUES to enter data for this module.

1 Specify the important crops which produce residues burned in fields and enter these as categories on the Worksheet.

2 For each type of crop, enter Annual Production in gigagrams, which is the same as kilotonnes, of crop product in column A.

3 Enter the Residue to Crop Ratio for each crop type in column B. Use Table 4-15 above if there are no local statistics.

4 Multiply the Annual Production of each crop by the Residue to Crop Ratio to give the Quantity of Residue. Enter the result in column C.

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 2 ESTIMATING THE AMOUNT OF DRY RESIDUE

1 Enter Dry Matter Fraction for each crop type in column D.

Default values for some crop types are shown in Table 4-15.

2 Multiply the Quantity of Residue by the Dry Matter Fraction to give the Quantity of Dry Residue in gigagrams of dry matter. Enter the result in column E.

STEP 3 ESTIMATING TOTAL BIOMASS BURNED

1 Enter the Fraction Burned in Fields for each crop type in column F.

Values should reflect an average of practices for the individual country. No default data are available.

2 Enter the Fraction Oxidised for each crop type in column G (default value 0.90).

3 Multiply the Quantity of Dry Residue by the Fraction Burned in Fields and the Fraction of Biomass Oxidised to give the Total Biomass Burned (in gigagrams of dry matter). Enter the result in column H.

STEP 4 CALCULATING THE TOTAL CARBON RELEASED

1 Enter the Carbon Fraction of each residue in column I.

Default values for some crop types are shown in Table 4-15. If no other information is available, use the general default for live biomass, which is 0.5.

2 Multiply the Total Biomass Burned by the Carbon Fraction of each residue to give the Total Carbon Released in gigagrams of carbon. Enter the results in column J.

3 Add the totals for each crop type in column J and enter the result in the Total box at the bottom of the column.

STEP 5 ESTIMATING TOTAL NITROGEN RELEASED

1 Enter the Nitrogen-Carbon Ratio for each crop type in column K.

The general default Nitrogen-Carbon ratio for crops is 0.01- 0.02. Some specific values for individual crops are given in Table 4-15.

2 Multiply the Total Carbon Released (column J) by the Nitrogen-Carbon Ratio (column K) to give the Total Nitrogen Released. Enter the result in column L.

3 Add the Total Nitrogen Released for each crop type and enter the result in the Total box at the bottom of column L.

STEP 6 ESTIMATING NON-CO_2 TRACE GAS EMISSIONS

1 Enter Emission Ratios in the relevant boxes in column M. Table 4-16 shows default emission ratios and ranges.

TABLE 4-16
DEFAULT EMISSION RATES FOR AGRICULTURAL RESIDUE BURNING CALCULATIONS

Gas	Ratios	
	Default	Range
CH_4	0.005	0.003-0.007
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 the nitrogen compounds are expressed as the ratios of mass of nitrogen compounds released relative to the total mass of nitrogen released from the fuel.

See the *Greenhouse Gas Inventory Reference Manual* for sources.

2 Multiply Carbon Released (Total from column J) by the Emission Ratios for CH_4 or CO (column M) to give the Emissions of Carbon as methane and carbon monoxide. Enter the results in the appropriate boxes in column N.

3 Multiply Nitrogen Released (Total from column L) by the Emission Ratios for N_2O or NO_x (column M) to give the Emissions of Nitrogen as nitrous oxide and nitrogen oxides. Enter the results in the appropriate boxes in column N.

4 For each gas, multiply by the Conversion Ratio[3] in column O to give the amount of Emissions from Burning Agricultural Residues. Enter the results, in gigagrams of each gas, in the appropriate boxes in column P.

[3] The molecular weight ratios given above for the emitted gases are with respect to the weight of nitrogen or 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.

4.6 Agricultural Soils

4.6.1 Introduction

Adequate information exists to calculate N_2O emissions from agricultural systems including (1) direct emissions of N_2O from agricultural soils (including glasshouse systems farming and excluding effects of grazing animals) (2) direct soil emissions of N_2O from animal production and (3) indirect emissions of N_2O from nitrogen used in agriculture. The calculations can be performed in 9 steps in Worksheet 4-5.

4.6.2 Data Sources

All input data can be obtained from FAO databases.

The following input data are needed:

- Total use of synthetic fertiliser in country (N_{FERT}, in kg N/yr).
- Number of livestock in country for the following categories: non-dairy cattle, dairy cattle, poultry, sheep, swine and other animals; $N_{(T)}$.
- Dry pulses and soybeans produced in country ($Crop_{BF}$, in kg/yr).
- Dry production of other crops in country ($Crop_0$, kg/yr).
- Area of cultivated organic soils (Histosols) in country (F_{OS}, ha).

4.6.3 Methodology

Total N_2O–N emissions from a country (kg N_2O–N/yr) are:

$$N_2O = N_2O_{DIRECT} + N_2O_{ANIMALS} + N_2O_{INDIRECT}$$

Completing the Worksheets

Use WORKSHEET 4-5, AGRICULTURAL SOILS at the end of this module to record the data.

ESTIMATING DIRECT NITROUS OXIDE EMISSIONS FROM AGRICULTURAL FIELDS

STEP 1 AMOUNT OF N INPUT

1 Calculation of synthetic fertiliser use (F_{SN})

The Worksheet calculations require the total synthetic fertiliser, F_{SN}, used in the country excluding emissions of NH_3 and NO_x (F_{SN}). This can be calculated from the following equation.

EQUATION 1

$$F_{SN} = N_{FERT} \times (1 - Frac_{GASF})$$

where:

N_{FERT} = total use of synthetic fertiliser in country (kg N/yr);

$Frac_{GASF}$ = fraction of total synthetic fertiliser nitrogen that is emitted as NO_x + NH_3 (kg N/kg N) (see Table 4-17).

Enter F_{SN} in Worksheet 4-5, sheet 1 in column A.

2 Calculation of nitrogen from animal waste (F_{AW})

The data needed are: livestock numbers in country for the following categories: non-dairy cattle, dairy cattle, poultry, sheep, swine and other animals, $N_{(T)}$.

Using nitrogen excretion factors as listed in Table 4-6, total nitrogen excretion by livestock can be calculated from livestock numbers. Table 4-7 shows the percentage of the manure-N used as fuel ($Frac_{FUEL}$), and from grazing animals (Pasture range and Paddock) ($Frac_{GRAZ}$).

EQUATION 2

$$F_{AW} = (Nex\ (1-(Frac_{FUEL} + Frac_{GRAZ} + Frac_{GASM}))$$

EQUATION 3

$$Nex = \sum [N_{(T)} \times Nex_{(T)}]$$

EQUATION 4

$$Nex_{(AWMS)} = \sum [N_{(T)} \times Nex_{(T)} \times AWMS_{(T)}]$$

where:

$AWMS_{(T)}$ = fraction of $Nex_{(T)}$ that is produced in the different distinguished animal waste management systems in country (from Tables 4-6 and 4-7);

F_{AW} = manure nitrogen used as fertiliser in country, corrected for NH_3 and NO_x emissions and excluding manure produced during grazing (kg N/yr);

$Frac_{FUEL}$ = fraction of livestock nitrogen excretion contained in excrements burned for fuel (kg N/kg N totally excreted);

$Frac_{GRAZ}$	=	fraction of livestock nitrogen excreted and deposited onto soil during grazing (kg N/kg N excreted); country estimate;
$Frac_{GASM}$	=	fraction of total nitrogen excretion that is emitted as NO_x or NH_3 (kg N/kg N) (see Table 4-17);
$N_{(T)}$	=	number of animals per Type of animal in country;
Nex	=	total nitrogen excretion by animals in country (kg N/yr);
$Nex_{(T)}$	=	nitrogen excretion per Type of animal in country (kg/yr) (see Table 4-6);
$Nex_{(AWMS)}$	=	nitrogen excretion per Animal Waste Management System (kg/yr).

Worksheet 4-5A (Supplemental) MANURE NITROGEN USED AS FERTILISER

Use Worksheet 4-5A (Supplemental) to calculate Manure Nitrogen Used as fertiliser, corrected for NH_3 and NO_x emissions and excluding manure produced during grazing.

1 Enter the Total Nitrogen Excretion, Nex for all AWMS from column A, sheet 3 Worksheet 4-1, into column A.

2 Enter the Fraction of Nitrogen burned for Fuel, $Frac_{FUEL}$, in column B. See Table 4-17 for default data.

3 Enter the Fraction of Nitrogen Excreted during Grazing, $Frac_{GRAZ}$, in column C. See Table 1 in Appendix A, Pasture Range and Paddock.

4 Enter the Fraction of Nitrogen Excreted Emitted as NO_x and NH_3, $Frac_{GASM}$, in column D. See Table 4-17 for default data. Note that the data in Appendix A are in per cent. Divide these values by 100 to obtain the Fraction of Nitrogen Excreted during Grazing.

5 Sum columns B, C and D and subtract the total from one. Enter this figure in column E.

6 Multiply columns A and E, and enter the result into column F to obtain the Manure Nitrogen Used (corrected for NH_3 and NO_x emission and excluding manure produced during grazing), F_{AW}, into column F.

7 Enter F_{AW} in Worksheet 4-5, sheet 1 in column A.

TABLE 4-17 SUMMARY OF DEFAULT VALUES FOR PARAMETERS		
$Frac_{BURN}$	=	0.25 in developing countries 0.10 or less in developed countries (kg N/kg crop-N)
$Frac_{FUEL}$	=	0.0 kg N/kg nitrogen excreted [a]
$Frac_{GASF}$	=	0.1 kg NH_3–N + NO_x–N/kg of synthetic fertiliser nitrogen applied
$Frac_{GASM}$	=	0.2 kg NH_3–N + NO_x–N/kg of nitrogen excreted by livestock
$Frac_{GRAZ}$	=	See Table A-1, Appendix A (Column Pasture Range and Paddock).[a]
$Frac_{LEACH}$	=	0.3 kg N/kg nitrogen of fertiliser or manure
$Frac_{NCRBF}$	=	0.03 kg N/kg of dry biomass
$Frac_{NCR0}$	=	0.015 kg N/kg of dry biomass
$Frac_R$	=	0.45 kg N/kg crop-N
[a] Countries are recommended to obtain country specific data.		

3. Calculation of total nitrogen input in N-fixing crops (F_{BN})

Nitrogen input from N-fixing crops (F_{BN}, kg N/yr) can be calculated from dry biomass production of pulses and soybean in country, $Crop_{BF}$ (kg/yr;):

EQUATION 5

$$F_{BN} = 2 \times Crop_{BF} \times Frac_{NCRBF}$$

where:

$Crop_{BF}$ = production of pulses + soybeans in country (kg dry biomass/yr);

$Frac_{NCRBF}$ = fraction of nitrogen in N-fixing crop (kg N/kg of dry biomass) (see Table 4-17). The factor 2 converts the FAO crop production to total crop biomass.

Enter F_{BN} in Worksheet 4-5, sheet 1 in column A.

4. Calculation of nitrogen input from crop residues (F_{CR})

Data needed to calculate nitrogen input from crop residues (F_{CR}) are:

- Dry biomass production of pulses and soybean in country, $Crop_{BF}$ (kg/yr)
- Dry biomass production of other crops in country, $Crop_0$ (kg/yr)

These numbers can be obtained from FAO databases.

Crop residue returned to soils (F_{CR}, in kg N/yr) is calculated as:

EQUATION 6

$$F_{CR} = 2 \times [Crop_0 \times Frac_{NCR0} + Crop_{BF} \times Frac_{NCRBF}] \times (1 - Frac_R) \times (1 - Frac_{BURN})$$

where:

$Crop_{BF}$	=	production of pulses + soybeans in country (kg dry biomass/yr);
$Crop_0$	=	production of non-N-fixing crops in country (kg dry biomass/yr);
$Frac_{NCRBF}$	=	fraction of nitrogen in N-fixing crops (kg N/kg of dry biomass) (see Table 4-17);
$Frac_{NCR0}$	=	fraction of nitrogen in non-N-fixing crops (kg N/kg of dry biomass) (see Table 4-17);
$Frac_R$	=	fraction of crop residue that is removed from the field as crop (kg N/kg crop-N) (see Table 4-17);
$Frac_{BURN}$	=	fraction of crop residue that is burned rather than left on field (see Table 4-17).

The factor 2 converts edible crop production to total crop biomass production.

Worksheet 4-5B (Supplemental) NITROGEN INPUT FROM CROP RESIDUES

Use Worksheet 4-5B (Supplemental) to calculate Nitrogen input from Crop Residues.

1 Enter the Production of non-N-fixing crops, $Crop_0$, in a country into column A. If production data are not available as dry biomass, multiply $Crop_0$ by (1-0.15) to account for crop water content.

2 Enter the Fraction of Nitrogen of non-N-fixing crops, $Frac_{NCR0}$, into column B. See Table 4-17 for default values.

3 Enter the Production of Pulses and Soybeans, $Crop_{BFN}$, into column C. If production data are not available as dry biomass, multiply $Crop_0$ by (1-0.15) to account for crop water content.

4 Enter the Fraction of Nitrogen in N-fixing crops, $Frac_{NCRBF}$ into column D. See Table 4-17 for default data.

5 Subtract the Fraction of Crop Residue Removed from Field, $Frac_R$, from one, and enter the result in column F. See Table 4-17 for default data.

6 Subtract the Fraction of Crop Residue Burnt, $Frac_{BURN}$, from one, and enter the result in column G. See Table 4-17 for default data.

7 Multiply columns A and B, and columns C with D. Sum the products, and multiply the result with the values in columns F and G. Multiply the result by 2 and enter the result into column H to obtain the nitrogen input from crop residues, F_{CR}.

8 Enter F_{CR} in Worksheet 4-5, sheet 1 in column A.

STEP 2 ESTIMATING DIRECT NITROUS OXIDE EMISSIONS EXCLUDING CULTIVATION OF HISTOSOLS

1 Enter Emission Factors for Direct Emissions in column B. Use default values for emission factor EF_1 provided in Table 4-18 or more precise locally available data.

2 Multiply the Amount of N input (column A) by the Emission Factor for Direct Emissions (column B) to give the Direct Soil emissions of N_2O. Multiply the final result by 10^{-6} to express it as gigagrams. Enter the results in column C.

3 Sum the Direct Soil Emissions and enter the total in the bottom of the column C.

STEP 3 ESTIMATING DIRECT N_2O EMISSIONS FROM CULTIVATION OF HISTOSOLS

1 Enter Area of Cultivated Organic Soils, F_{os} , in column D.

2 Enter Emission Factor for Direct Soil Emissions in column E. Use default values for Emission Factor, EF_2 provided in Table 4-18 or more precise locally available data.

3 Multiply the Area of Cultivated Organic Soils (column D) by Emission Factor for Direct Soil Emissions (column E) to give the total Direct Emissions from Histosols. Multiply the final result by 10^{-6} to express it as gigagrams. Enter the result in column F.

TABLE 4-18
SUMMARY OF DEFAULT EMISSION FACTORS FOR AGRICULTURAL EMISSIONS OF N_2O

EF_1	=	0.0125 (0.0025-0.0225) kg N_2O–N/kg nitrogen input
EF_2	=	5 temperate and 10 tropical (2-15) (kg N/ha/yr)
EF_3	=	see Table 4-8
EF_4	=	0.01 (0.002-0.02) kg N_2O–N per kg NH_3–N and NO_x–N emitted
EF_5	=	0.025 (0.002-0.12) kg N_2O–N per kg nitrogen leaching/runoff
EF_6	=	0.01 (0.002-0.12) kg N_2O–N per kg sewage-N produced

STEP 4 ESTIMATING TOTAL DIRECT N_2O EMISSIONS

Direct N_2O emissions can be calculated from the following equation:

EQUATION 7

$$N_2O_{DIRECT} \text{ (kg N/yr)} = [F_{SN} + F_{AW} + F_{CR} + F_{BN}] \times EF_1 + F_{OS} \times EF_2$$

1 Add the two totals from columns C and F together and then multiply by the conversion ratio 44/28 to give the Total Direct N_2O Emissions. Enter the result in column G.

STEP 5 ESTIMATING SOIL EMISSIONS OF N_2O FROM GRAZING ANIMALS

Only emissions from pasture range and paddock are reported here. The N_2O emissions from other Waste Management Systems are reported under Manure Management (Worksheet 4-1, sheet 2). N_2O emissions from grazing animals ($N_2O_{ANIMALS}$ in kg N/yr) can be calculated as follows:

EQUATION 8

$$N_2O_{ANIMALS} = N_2O_{(AWMS)} = \Sigma_{(T)}[N_{(T)} \times Nex_{(T)} \times AWMS_{(T)} \times EF_{3(AWMS)}]$$

where:

$N_2O_{ANIMALS}$ = N_2O emissions from animal production in a country (kg N/yr);

$N_2O_{(AWMS)}$ = N_2O emissions from Animal Waste Management Systems in the country (kg N/yr);

= $[N_{(T=1)} \times Nex_{(T=1)} \times AWMS_{(T=1)} \times EF_{3(AWMS)}] + \ldots + [N_{(T=TMAX)} \times Nex_{(T=TMAX)} \times AWMS_{(T=TMAX)} \times EF_{3(AWMS)}]$;

$N_{(T)}$ = number of animals of type T in the country;

$Nex_{(T)}$ = N excretion of animals of type T in the country (kg N/animal /yr); (see Table 4-6);

$AWMS_{(T)}$ = fraction of $Nex_{(T)}$ that is managed in one of the different distinguished animal waste management systems for animals of type T in the country; (see Table 4-7);

$EF_{3(AWMS)}$ = N_2O emission factor for an AWMS (kg N_2O-N/kg of Nex in AWMS); (see Table 4-8);

T = type of animal category;

T_{MAX} = maximum types of animals distinguished in the country.

1 Enter Nitrogen Excretion, $Nex_{(AWMS)}$, value for Pasture Range and Paddock (from Worksheet 4-1 Supplemental) into column A.

2 Enter Emission Factor for AWMS in column B. Use default values for Emission Factors, EF_3, provided in Table 4-18 or more precise locally available data.

3 Multiply $Nex_{(AWMS)}$ (column A) by the Emission Factor (column B) and then by the conversion ratio 44/28 to give Emissions of Nitrous Oxide from Grazing Animals. Multiply the final result by 10^{-6} to express it as gigagrams. Enter the result in column C.

STEP 6 ESTIMATING INDIRECT EMISSIONS FROM ATMOSPHERIC DEPOSITION OF NH_3 AND NO_x

1 Enter the total amount of Synthetic Fertiliser N Applied to Soil, $N_{(FERT)}$, in column A.

2 Enter the Fraction of Synthetic Fertiliser N Applied that Volatilizes ($Frac_{GASFS}$) in column B. Use default values provided in Table 4-17 or more precise locally available data.

3 Multiply the total Amount of Synthetic Fertiliser Applied in the country (column A) by the Fraction of Synthetic Fertiliser N Applied that Volatilizes (column B) to give the total Amount of Synthetic Fertiliser Applied to Soil that Volatilizes. Enter the result in column C.

4 Enter the Total N Excretion by Livestock (Nex) calculated using equation 3 in column D.

5 Enter the Fraction of Total Manure N Excreted that Volatilizes ($Frac_{GASM}$) in column E. Use default values provided in Table 4-17 or more precise locally available data.

6 Multiply the Total N Excretion by Livestock, (Nex), (column D) by Fraction of Total Manure N Excreted that Volatilizes, $Frac_{GASM}$, (column E). Enter the result in column F.

7 Enter Emission Factor, EF_4, in column G. Use default values provided in Table 4-18 or more precise locally available data.

8 Add columns C and F and then multiply by Emission Factor, EF_4, (column G) to give Nitrous Oxide Emissions. Multiply the final result by 10^{-6} to express it as gigagrams. Enter the result in column H.

STEP 7 ESTIMATING INDIRECT EMISSIONS FROM LEACHING

1 Enter the total amount of Synthetic Fertiliser Use in the country $N_{(FERT)}$ in column I.

2 Enter the total Livestock N Excretion (Nex), calculated using Equation 3, in column J.

3 Enter the Fraction of N that Leaches, $Frac_{LEACH}$, in column K. Use default values provided in Table 4-17 or more precise locally available data.

4 Enter the Emission Factor, EF_5, in column L. Use default values provided in Table 4-18 or more precise locally available data.

5 Add total amount of Synthetic Fertiliser Use in the country $N_{(FERT)}$ (column I) to Nex (column J). Multiply by $Frac_{LEACH}$ (column K) and then by EF_5 (column L) to give the indirect Nitrous Oxide Emissions from Leaching. Multiply the final result by 10^{-6} to express it as gigagram. Enter the result in column M.

STEP 8 ESTIMATING INDIRECT EMISSIONS

Indirect N_2O emissions (kg/yr) can now be calculated in Worksheet 4-5, Sheets 1 (atmospheric deposition), and 2 (leaching and runoff) as:

EQUATION 9

$$N_2O_{INDIRECT} = N_2O_{(G)} + N_2O_{(L)}$$

where:

$N_2O_{(G)}$ = $(N_{FERT} \times Frac_{GASF} + Nex\ Frac_{GASM}) \times EF_4$;

$N_2O_{(L)}$ = $(N_{FERT} + Nex) \times Frac_{LEACH} \times EF_5$.

where:

$Frac_{LEACH}$ = fraction of nitrogen input to soils that is lost through leaching and runoff (kg N/kg of nitrogen applied); (see Table 4-19);

$N_2O_{INDIRECT}$ = indirect N_2O emissions from country (kg N/yr);

$N_2O_{(G)}$ = N_2O emissions from country due to atmospheric deposition of NH_3 and NO_x (kg N/yr);

$N_2O_{(L)}$ = N_2O emissions from country due to nitrogen leaching and runoff (kg N/yr).

1 Sum the two totals in columns H and M and then multiply by the conversion ratio 44/28 to give the Total Indirect Nitrous Oxide Emissions. Enter the result in column N.

STEP 9 TOTAL N_2O EMISSIONS FROM AGRICULTURAL SOILS

Total Nitrous Oxide Emissions from agricultural soils can be calculated as the sum of direct emissions (Worksheet 4-5, sheet 2, step 4), emissions from animal waste (Worksheet 4-5, sheet 3, step 5) and indirect emissions (Worksheets 4-5, sheet 5, step 8). Thus

Total N_2O–N emissions from a country (kg N_2O–N/yr) are:

EQUATION 10

$$N_2O = N_2O_{DIRECT} + N_2O_{ANIMALS} + N_2O_{INDIRECT}$$

1 Sum the totals in column G (Worksheet 4-5, sheet 2, step 4), column C (Worksheet 4-5, sheet 3, step 5) and column N (Worksheet 4-5, sheet 5, step 8) to give the Total Nitrous Oxide Emissions from agricultural soils. Enter the result in column O.

TABLE 4-19
DEFAULT VALUES OF PARAMETERS FOR INDIRECT EMISSIONS

$Frac_{NPR}$	0.16 kg N/kg of protein
$Frac_{LEACH}$	0.3 (0.1-0.8) kg N/kg of fertiliser or manure N

Appendix A

Data Underlying Nitrous Oxide Emissions from Agricultural Soils

This appendix presents the data used to calculate the manure-N excretion and N_2O emission factors in Table A-1.

TABLE A-1

CALCULATION OF MANURE-N EXCRETION AND N_2O EMISSION FACTORS FOR DIFFERENT ANIMAL WASTE MANAGEMENT SYSTEMS IN DIFFERENT WORLD REGIONS. THESE ARE TO BE REPORTED UNDER MANURE MANAGEMENT, EXCEPT FOR DAILY SPREAD AND PASTURE RANGE OF PADDOCK (EMISSIONS FROM AGRICULTURAL SOILS) AND EMISSIONS AFTER USE AS A FUEL (ENERGY)

Region	Type of Animal			Emission Factor for AWMSs EF_3 (% of Manure N Excreted that is lost as N_2O)							
		Number of Animals ($\times 10^6$)	Nitrogen Excretion kg N/animal/yr	Anaerobic Lagoon (EF_3)	Liquid Systems (EF_3)	Daily Spread (EF_3)	Solid Storage & Drylot (EF_3)	Pasture Range Paddock (EF_3)	Used Fuel (EF_3)	Other System (EF_3)	Total N Excreted (Tg N)
North America	Non-dairy Cattle	99.199	70	0.1	0.1	0.0	2.0	2.0	0.0	0.5	6.9
	Dairy Cattle	16.521	100	0.1	0.1	0.0	2.0	2.0	0.0	0.5	1.7
	Poultry (E)	1486.266	0.6	0.1	0.1	0.0	2.0	2.0	0.0	0.5	0.9
	Sheep	11.336	16	0.1	0.1	0.0	2.0	2.0	0.0	0.5	0.2
	Swine	66.146	20	0.1	0.1	0.0	2.0	2.0	0.0	0.5	1.3
	Other animals (F)	6.067	25	0.1	0.1	0.0	2.0	2.0	0.0	0.5	0.2
Western Europe	Non-dairy Cattle	56.618	70	0.1	0.1	0.0	2.0	2.0	0.0	0.5	4.0
	Dairy Cattle	31.099	100	0.1	0.1	0.0	2.0	2.0	0.0	0.5	3.1
	Poultry (E)	880.000	0.6	0.1	0.1	0.0	2.0	2.0	0.0	0.5	0.5
	Sheep	93.856	20	0.1	0.1	0.0	2.0	2.0	0.0	0.5	1.9
	Swine	114.959	20	0.1	0.1	0.0	2.0	2.0	0.0	0.5	2.3
	Other animals (F)	31.578	25	0.1	0.1	0.0	2.0	2.0	0.0	0.5	0.8
Eastern Europe	Non-dairy Cattle	101.447	50	0.1	0.1	0.0	2.0	2.0	0.0	0.5	5.1
	Dairy Cattle	56.800	70	0.1	0.1	0.0	2.0	2.0	0.0	0.5	4.0
	Poultry (E)	1667.000	0.6	0.1	0.1	0.0	2.0	2.0	0.0	0.5	1.0
	Sheep	188.159	16	0.1	0.1	0.0	2.0	2.0	0.0	0.5	3.0
	Swine	152.757	20	0.1	0.1	0.0	2.0	2.0	0.0	0.5	3.1
	Other animals (F)	21.558	25	0.1	0.1	0.0	2.0	2.0	0.0	0.5	0.5

TABLE A-1 (CONTINUED)
CALCULATION OF MANURE-N EXCRETION AND N2O EMISSION FACTORS FOR DIFFERENT ANIMAL WASTE MANAGEMENT SYSTEMS IN DIFFERENT WORLD REGIONS. THESE ARE TO BE REPORTED UNDER MANURE MANAGEMENT, EXCEPT FOR DAILY SPREAD AND PASTURE RANGE OF PADDOCK (EMISSIONS FROM AGRICULTURAL SOILS) AND EMISSIONS AFTER USE AS A FUEL (ENERGY)

Region	Type of Animal			Emission Factor for AWMSs EF_3 (% of Manure N Excreted that is lost as N_2O)							
		Number of Animals ($\times 10^6$)	Nitrogen Excretion kg N/animal/yr	Anaerobic Lagoon (EF_3)	Liquid Systems (EF_3)	Daily Spread (EF_3)	Solid Storage & Drylot (EF_3)	Pasture Range Paddock (EF_3)	Used Fuel (EF_3)	Other System (EF_3)	Total N Excreted. (Tg N)
Oceania	Non-dairy Cattle	27.610	60	0.1	0.1	0.0	2.0	2.0	0.0	0.5	1.7
	Dairy Cattle	4.441	80	0.1	0.1	0.0	2.0	2.0	0.0	0.5	0.4
	Poultry (E)	71.000	0.6	0.1	0.1	0.0	2.0	2.0	0.0	0.5	0.0
	Sheep	228.982	20	0.1	0.1	0.0	2.0	2.0	0.0	0.5	4.6
	Swine	5.003	16	0.1	0.1	0.0	2.0	2.0	0.0	0.5	0.1
	Other animals (F)	2.579	25	0.1	0.1	0.0	2.0	2.0	0.0	0.5	0.1
Latin America	Non-dairy Cattle	272.871	40	0.1	0.1	0.0	2.0	2.0	0.0	0.5	10.9
	Dairy Cattle	37.560	70	0.1	0.1	0.0	2.0	2.0	0.0	0.5	2.6
	Poultry (E)	1259.000	0.6	0.1	0.1	0.0	2.0	2.0	0.0	0.5	0.8
	Sheep	117.312	12	0.1	0.1	0.0	2.0	2.0	0.0	0.5	1.4
	Swine	78.150	16	0.1	0.1	0.0	2.0	2.0	0.0	0.5	1.3
	Other animals (F)	71.699	40	0.1	0.1	0.0	2.0	2.0	0.0	0.5	2.9
Africa	Non-dairy Cattle	133.198	40	0.1	0.1	0.0	2.0	2.0	0.0	0.5	5.3
	Dairy Cattle	18.734	60	0.1	0.1	0.0	2.0	2.0	0.0	0.5	1.1
	Poultry (E)	646.000	0.6	0.1	0.1	0.0	2.0	2.0	0.0	0.5	0.4
	Sheep	179.171	12	0.1	0.1	0.0	2.0	2.0	0.0	0.5	2.2
	Swine	12.445	16	0.1	0.1	0.0	2.0	2.0	0.0	0.5	0.2
	Other animals (F)	162.194	40	0.1	0.1	0.0	2.0	2.0	0.0	0.5	6.5

TABLE A-1 (CONTINUED)
CALCULATION OF MANURE-N EXCRETION AND N_2O EMISSION FACTORS FOR DIFFERENT ANIMAL WASTE MANAGEMENT SYSTEMS IN DIFFERENT WORLD REGIONS. THESE ARE TO BE REPORTED UNDER MANURE MANAGEMENT, EXCEPT FOR DAILY SPREAD AND PASTURE RANGE OF PADDOCK (EMISSIONS FROM AGRICULTURAL SOILS) AND EMISSIONS AFTER USE AS A FUEL (ENERGY)

Region	Type of Animal			Emission Factor for AWMSs EF_3 (% of Manure N Excreted that is lost as N_2O)							
		Number of Animals (x 10^6)	Nitrogen Excretion (kg N/animal/yr)	Anaerobic Lagoon (EF_3)	Liquid Systems (EF_3)	Daily Spread (EF_3)	Solid Storage & Drylot (EF_3)	Pasture range Paddock (EF_3)	Used Fuel (EF_3)	Other System (EF_3)	Total N Excreted (Tg N)
Near East and Mediterranean	Non-dairy Cattle	44.562	50	0.1	0.1	0.0	2.0	2.0	0.0	0.5	2.2
	Dairy Cattle	17.174	70	0.1	0.1	0.0	2.0	2.0	0.0	0.5	1.2
	Poultry (E)	656.000	0.6	0.1	0.1	0.0	2.0	2.0	0.0	0.5	0.4
	Sheep	187.502	12	0.1	0.1	0.0	2.0	2.0	0.0	0.5	2.3
	Swine	0.174	16	0.1	0.1	0.0	2.0	2.0	0.0	0.5	0.0
	Other animals (F)	81.962	40	0.1	0.1	0.0	2.0	2.0	0.0	0.5	3.3
Asia and Far East	Non-dairy Cattle	440.398	40	0.1	0.1	0.0	2.0	2.0	0.0	0.5	17.6
	Dairy Cattle	45.240	60	0.1	0.1	0.0	2.0	2.0	0.0	0.5	2.7
	Poultry (E)	3949.000	0.6	0.1	0.1	0.0	2.0	2.0	0.0	0.5	2.4
	Sheep	202.442	12	0.1	0.1	0.0	2.0	2.0	0.0	0.5	2.4
	Swine	403.231	16	0.1	0.1	0.0	2.0	2.0	0.0	0.5	6.5
	Other animals (F)	293.700	40	0.1	0.1	0.0	2.0	2.0	0.0	0.5	11.7
World Total											135.3

(D) Includes buffalo
(E) Includes chickens, turkeys and ducks
(F) Includes goats, horses, mules, donkeys and camels

MODULE	**AGRICULTURE**
SUBMODULE	**METHANE AND NITROUS OXIDE EMISSIONS FROM DOMESTIC LIVESTOCK ENTERIC FERMENTATION AND MANURE MANAGEMENT**
WORKSHEET	**4-1**
SHEET	**1 OF 2 METHANE EMISSIONS FROM DOMESTIC LIVESTOCK ENTERIC FERMENTATION AND MANURE MANAGEMENT**

	STEP 1			**STEP 2**		**STEP 3**
Livestock Type	A Number of Animals (1000s)	B Emissions Factor for Enteric Fermentation (kg/head/yr)	C Emissions from Enteric Fermentation (t/yr)	D Emissions Factor for Manure Management (kg/head/yr)	E Emissions from Manure Management (t/yr)	F Total Annual Emissions from Domestic Livestock (Gg)
			C = (A x B)		E = (A x D)	F =(C + E)/1000
Dairy Cattle						
Non-dairy Cattle						
Buffalo						
Sheep						
Goats						
Camels						
Horses						
Mules & Asses						
Swine						
Poultry						
Totals						

MODULE	**AGRICULTURE**
SUBMODULE	**METHANE AND NITROUS OXIDE EMISSIONS FROM DOMESTIC LIVESTOCK ENTERIC FERMENTATION AND MANURE MANAGEMENT**
WORKSHEET	**4-1 (SUPPLEMENTAL)**
SPECIFY AWMS	
SHEET	**NITROGEN EXCRETION FOR ANIMAL WASTE MANAGEMENT SYSTEM**

Livestock Type	A Number of Animals (1000s)	B Nitrogen Excretion Nex (kg//head/(yr)	C Fraction of Manure Nitrogen per AWMS (%/100) (fraction)	D Nitrogen Excretion per AWMS, Nex (kg/N/yr)
				D = (A x B x C)
Non-dairy Cattle				
Dairy Cattle				
Poultry				
Sheep				
Swine				
Others				
			TOTAL	

MODULE	AGRICULTURE		
SUBMODULE	METHANE AND NITROUS OXIDE EMISSIONS FROM DOMESTIC LIVESTOCK ENTERIC FERMENTATION AND MANURE MANAGEMENT		
WORKSHEET	4-1		
SHEET	2 OF 2 NITROUS OXIDE EMISSIONS FROM ANIMAL PRODUCTION EMISSIONS FROM ANIMAL WASTE MANAGEMENT SYSTEMS (AWMS)		
STEP 4			
Animal Waste Management System (AWMS)	A Nitrogen Excretion $Nex_{(AWMS)}$ (kg N/yr)	B Emission Factor For AWMS EF_3 (kg N_2O–N/kg N)	C Total Annual Emissions of N_2O (Gg)
			$C= (A \times B)[44/28] \times 10^{-6}$
Anaerobic lagoons			
Liquid systems			
Daily spread			
Solid storage & drylot			
Pasture range and paddock			
Other			
Totals			

MODULE	AGRICULTURE
SUBMODULE	METHANE EMISSIONS FROM FLOODED RICE FIELDS
WORKSHEET	4-2
SHEET	1 OF 1

Water Management Regime			A Harvested Area ($m^2 \times 10^{-9}$)	B Scaling Factor for Methane Emissions	C Correction Factor for Organic Amendment	D Seasonally Integrated Emission Factor for Continuously Flooded Rice without Organic Amendment (g/m^2)	E CH_4 Emissions (Gg)
							E = (A x B x C x D)
Irrigated	Continuously Flooded						
	Intermittently Flooded	Single Aeration					
		Multiple Aeration					
Rainfed	Flood Prone						
	Drought Prone						
Deep Water	Water Depth 50-100 cm						
	Water Depth > 100 cm						
Totals							

			MODULE	AGRICULTURE			
			SUBMODULE	PRESCRIBED BURNING OF SAVANNAS			
			WORKSHEET	4-3			
			SHEET	1 OF 3			
STEP 1					STEP 2		
A Area Burned by Category (specify) (k ha)	B Biomass Density of Savanna (t dm/ha)	C Total Biomass Exposed to Burning (Gg dm)	D Fraction Actually Burned	E Quantity Actually Burned (Gg dm)	F Fraction of Living Biomass Burned	G Quantity of Living Biomass Burned (Gg dm)	H Quantity of Dead Biomass Burned (Gg dm)
		C = (A x B)		E = (C x D)		G = (E x F)	H = (E - G)

MODULE	AGRICULTURE
SUBMODULE	PRESCRIBED BURNING OF SAVANNAS
WORKSHEET	4-3
SHEET	2 OF 3

STEP 3

I Fraction Oxidised of living and dead biomass	J Total Biomass Oxidised (Gg dm)	K Carbon Fraction of Living & Dead Biomass	L Total Carbon Released (Gg C)
	Living: J = (G x I) *Dead:* J = (H x I)		L = (J x K)
Living			
Dead			
Living			
Dead			
Living			
Dead			
Living			
Dead			
Living			
Dead			
Living			
Dead			
Living			
Dead			
Total			

			MODULE	**AGRICULTURE**		
			SUBMODULE	**PRESCRIBED BURNING OF SAVANNAS**		
			WORKSHEET	**4-3**		
			SHEET	**3 OF 3**		
STEP 4					**STEP 5**	
L Total Carbon Released (Gg C)	M Nitrogen-Carbon Ratio	N Total Nitrogen Content (Gg N)	O Emissions Ratio	P Emissions (Gg C **or** Gg N)	Q Conversion Ratio	R Emissions from Savanna Burning (Gg)
		N = (L x M)		P = (L x O)		R = (P x Q)
					16/12	*CH_4*
					28/12	*CO*
				P = (N x O)		R = (P x Q)
					44/28	*N_2O*
					46/14	*NO_x*

			MODULE	AGRICULTURE				
			SUBMODULE	FIELD BURNING OF AGRICULTURAL RESIDUES				
			WORKSHEET	4-4				
			SHEET	1 OF 3				
	STEP 1			STEP 2		STEP 3		
Crops (specify locally important crops)	A Annual Production (Gg crop)	B Residue to Crop Ratio	C Quantity of Residue (Gg biomass)	D Dry Matter Fraction	E Quantity of Dry Residue (Gg dm)	F Fraction Burned in Fields	G Fraction Oxidised	H Total Biomass Burned (Gg dm)
			C = (A x B)		E = (C x D)			H = (E x F xG)
Total:								

MODULE	**AGRICULTURE**
SUBMODULE	**FIELD BURNING OF AGRICULTURAL RESIDUES**
WORKSHEET	**4-4**
SHEET	**2 OF 3**

	STEP 4		**STEP 5**	
	I Carbon Fraction of Residue	J Total Carbon Released (Gg C)	K Nitrogen-Carbon Ratio	L Total Nitrogen Released (Gg N)
		J = (H x I)		L = (J x K)
Total:				

MODULE	**AGRICULTURE**
SUBMODULE	**FIELD BURNING OF AGRICULTURAL RESIDUES**
WORKSHEET	**4-4**
SHEET	**3 OF 3**

STEP 6

	M Emission Ratio	N Emissions (Gg C **or** Gg N)	O Conversion Ratio	P Emissions from Field Burning of Agricultural Residues (Gg)
		N = (J x M)		P = (N x O)
CH_4			16/12	
CO			28/12	
		N = (L x M)		P = (N x O)
N_2O			44/28	
NO_x			46/14	

MODULE	**AGRICULTURE**
SUBMODULE	**AGRICULTURAL SOILS**
WORKSHEET	**4-5**
SHEET	**1 OF 5 DIRECT NITROUS OXIDE EMISSIONS FROM AGRICULTURAL FIELDS, EXCLUDING CULTIVATION OF HISTOSOLS**

	STEP 1	**STEP 2**	
Type of N input to soil	A Amount of N Input (kg N/yr)	B Emission Factor for Direct Emissions EF_1 (kg N_2O–N/kg N)	C Direct Soil Emissions (Gg N_2O-N/yr)
			$C = (A \times B) \times 10^{-6}$
Synthetic fertiliser (F_{SN})			
Animal waste (F_{AW})			
N-fixing crops (F_{BN})			
Crop residue (F_{CR})			
		Total	

MODULE	**AGRICULTURE**
SUBMODULE	**AGRICULTURAL SOILS**
WORKSHEET	**4-5A (SUPPLEMENTAL)**
SHEET	**1 OF 1 MANURE NITROGEN USED**

A Total Nitrogen Excretion (kg N/yr)	B Fraction of Nitrogen Burned for Fuel (fraction)	C Fraction of Nitrogen Excreted During Grazing (fraction)	D Fraction of Nitrogen Excreted Emitted as NO_X and NH_3 (fraction)	E Sum (fraction)	F Manure Nitrogen Used (corrected for NO_X and NH_3 emissions), F_{AW} (kg N/yr)
				F = 1 - (B + C + D)	F = (A x E)

MODULE	**AGRICULTURE**
SUBMODULE	**AGRICULTURAL SOILS**
WORKSHEET	**4-5B (SUPPLEMENTAL)**
SHEET	**1 OF 1 NITROGEN INPUT FROM CROP RESIDUES**

A Production of non - N - Fixing Crops (kg dry biomass/yr)	B Fraction of Nitrogen of non - N - Fixing Crops, (kg N/kg dry biomass)	C Production of Pulses and Soybeans (kg dry biomass/yr)	D Fraction of Nitrogen in N-Fixing Crops, (kg N/kg dry biomass)	E One minus the Fraction of Crop Residue Removed From Field, (fraction)	F One minus the Fraction of Crop Residue Burned (fraction)	G Nitrogen Input from Crop Residues (kg N/yr)
						G = 2 x (A x B + C x D) x E x F

MODULE	**AGRICULTURE**			
SUBMODULE	**AGRICULTURAL SOILS**			
WORKSHEET	**4-5**			
SHEET	**2 OF 5 DIRECT NITROUS OXIDE EMISSIONS FROM CULTIVATION OF HISTOSOLS**			
	STEP 3			**STEP 4**
	D Area of Cultivated Organic Soils F_{OS} (ha)	E Emission Factor for Direct Soil Emissions EF_2 (kg N_2O–N/ha/yr)	F Direct Emissions from Histosols (Gg N_2O–N/yr)	G Total Direct Emissions of N_2O (Gg)
			$F=(D \times E)\times 10^{-6}$	$G = (C+F)[44/28]$
Subtotal				

MODULE	**AGRICULTURE**		
SUBMODULE	**AGRICULTURAL SOILS**		
WORKSHEET	**4-5**		
SHEET	**3 OF 5 NITROUS OXIDE SOIL EMISSIONS FROM GRAZING ANIMALS - PASTURE RANGE AND PADDOCK**		
	STEP 5		
Animal Waste Management System (AWMS)	A Nitrogen Excretion $Nex_{(AWMS)}$ (kg N/yr)	B Emission Factor for AWMS EF_3 (kg N_2O–N/kg N)	C Emissions Of N_2O from Grazing Animals (Gg)
			$C = (A \times B)[44/28]\times 10^{-6}$
Pasture range & paddock			

MODULE	AGRICULTURE							
SUBMODULE	AGRICULTURAL SOILS							
WORKSHEET	4-5							
SHEET	4 OF 5 INDIRECT NITROUS OXIDE EMISSIONS FROM ATMOSPHERIC DEPOSITION OF NH_3 AND NO_X							
	STEP 6							
Type of Deposition	A Synthetic Fertiliser N Applied to Soil, N_{FERT} (kg N/yr)	B Fraction of Synthetic Fertiliser N Applied that Volatilizes $Frac_{GASFS}$ (kg N/kg N)	C Amount of Synthetic N Applied to Soil that Volatilizes (kg N/kg N)	D Total N Excretion by Livestock N_{EX} (kg N/yr)	E Fraction of Total Manure N Excreted that Volatilizes $Frac_{GASM}$ (kg N/kg N)	F Total N Excretion by Livestock that Volatilizes (kg N/kg N)	G Emission Factor EF_4 (kg N_2O–N/kg N)	H Nitrous Oxide Emissions (Gg N_2O–N/yr)
			C = (A x B)			F = (D x E)		H = (C + F) x G x10-6
Total								

MODULE	**AGRICULTURE**						
SUBMODULE	**AGRICULTURAL SOILS**						
WORKSHEET	**4-5**						
SHEET	**5 OF 5 INDIRECT NITROUS OXIDE EMISSIONS FROM LEACHING**						
	STEP 7					**STEP 8**	**STEP 9**
	I Synthetic Fertiliser Use N_{FERT} (kg N/yr)	J Livestock N Excretion N_{EX} (kg N/yr)	K Fraction of N That Leaches $Frac_{LEACH}$ (kg N/kg N)	L Emission Factor EF_5	M Nitrous Oxide Emissions From Leaching (Gg N_2O–N/yr)	N Total Indirect Nitrous Oxide Emissions (Gg N_2O/yr)	O Total Nitrous Oxide Emissions (Gg)
					$M = (I + J) \times K \times L \times 10^{-6}$	$N = (H + M)[44/28]$	$O = (G + C + N)$ (G from Worksheet 4-5, sheet 2, Step 4; C from Worksheet 4-5, sheet 3, Step 5; N from Worksheet 4-5, sheet 5, Step 8).
Total							