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 Non-dairy	118 47	Average milk production of 6700 kg/head/yr 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 Non-dairy	100 48	Average milk production of 4200 kg/head /yr 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 Non-dairy	81 56	Average milk production of 2550 kg/head/yr 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 Non-dairy	68 53	Average milk production of 1700 kg/head/yr 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 Non-dairy	57 49	Average milk production of 800 kg/head/yr 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 Non-dairy Cattle Swine	36 1 10	54 2 14	76 3 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 Non-dairy Cattle Swine Buffalo	14 6 3 3	44 20 10 8	81 38 19 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 Non-dairy Cattle Swine Buffalo	6 4 4 3	19 13 7 9	33 23 11 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 Non-dairy Cattle Swine	31 5 20	32 6 20	33 7 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 Non-dairy Cattle Swine Buffalo	0 1 0 1	1 1 1 1	2 1 2 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 Non-dairy Cattle Swine Buffalo	7 1 1 1	16 1 4 2	27 2 7 3
Africa: Almost all livestock manure is managed as a solid on pastures and ranges.	Dairy Cattle Non-dairy Cattle Swine	1 0 0	1 1 1	1 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

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.

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.

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).