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METHODS FOR ESTIMATING METHANE EMISSIONS FROM RICE CULTIVATION

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INTRODUCTION

The EIIP guidelines are designed to describe emission estimation techniques for greenhouse gas sources in a clear and unambiguous manner and to facilitate preparation of inventories at the state level. This chapter presents the methodology for estimating methane emissions from rice cultivation. The methodology presented in this chapter has been revised to reflect new activity data, emission factors, and methods pertaining to this source category. Where possible, the methodology has been updated to be consistent with the *Inventory of United States Greenhouse Gas Emissions and Sinks: 1990-2002*.

Section 2 of this chapter contains a general description of this source category. Section 3 provides a listing of the steps involved in estimating methane emissions from rice cultivation. Section 4 presents the preferred estimation method. Section 5 is a placeholder for alternative estimation techniques that may be added in the future. A summary of uncertainty for this source category is provided in Section 6. References used in developing this chapter are identified in Section 7.

In addition to these guidelines, there are a series of user friendly spreadsheet tools available to assist in the development of emission inventories at the state level. Please consult the Agriculture Module of the State Inventory Tool[1] to calculate emissions from this source category using the preferred emission estimation method.

[1] Note: The spreadsheet tool may have a different order of calculations, and may not show all calculations to the user.

2

SOURCE CATEGORY DESCRIPTION

2.1 EMISSION SOURCES

Most of the world's rice, and all of the rice in the United States,[2] is grown on flooded fields. When fields are flooded, aerobic decomposition of organic material gradually depletes the oxygen present in the soils and floodwater, and anaerobic conditions develop in the soils. At that point, methane (CH_4) is produced through anaerobic decomposition of organic matter by methanogenic bacteria. However, not all of the CH_4 that is produced is released into the atmosphere. As much as 60 to 80 percent of the methane produced is oxidized by aerobic methanotrophic bacteria in the soils (Holzapfel-Pschorn et al. 1985, Sass et al. 1990). Some of the CH_4 is also leached to ground water as dissolved CH_4. The remaining non-oxidized CH_4 is transported from the soil to the atmosphere primarily by diffusive transport through the rice plants. Some CH_4 also escapes from the soil via diffusion and bubbling through the floodwaters. Figure 9.2-1 graphically depicts the process of CH_4 production and its emissions.

Rice cultivation is a very small source of CH_4 in the United States. In 2000, CH_4 emissions from this source are estimated to have been approximately 2.05 million metric tons of carbon equivalent (U.S. EPA 2002). This represents approximately 1 percent of total United States CH_4 emissions from anthropogenic sources, and about 4 percent of United States CH_4 emissions from agricultural sources.

This source category accounts for only some of the many agricultural and forestry activities that emit greenhouse gases. Table 9.2-1 summarizes the agricultural and forestry activities associated with emissions of carbon dioxide, CH_4, and nitrous oxide, and provides a roadmap indicating the chapter in which each activity is addressed.

2.2 FACTORS INFLUENCING EMISSIONS

The water management system under which rice is grown is one of the most important factors affecting CH_4 emissions. Upland rice fields are not flooded,[3] and therefore are not believed to produce CH_4. In deepwater rice fields (i.e., fields with flooding depths greater than approximately 3.3 feet), the lower stems and roots of the rice plants do not transport CH_4, thus blocking this primary pathway of CH_4 emissions. Therefore, while deepwater rice growing areas are believed to emit CH_4, the quantities released are likely to be significantly lower than in areas

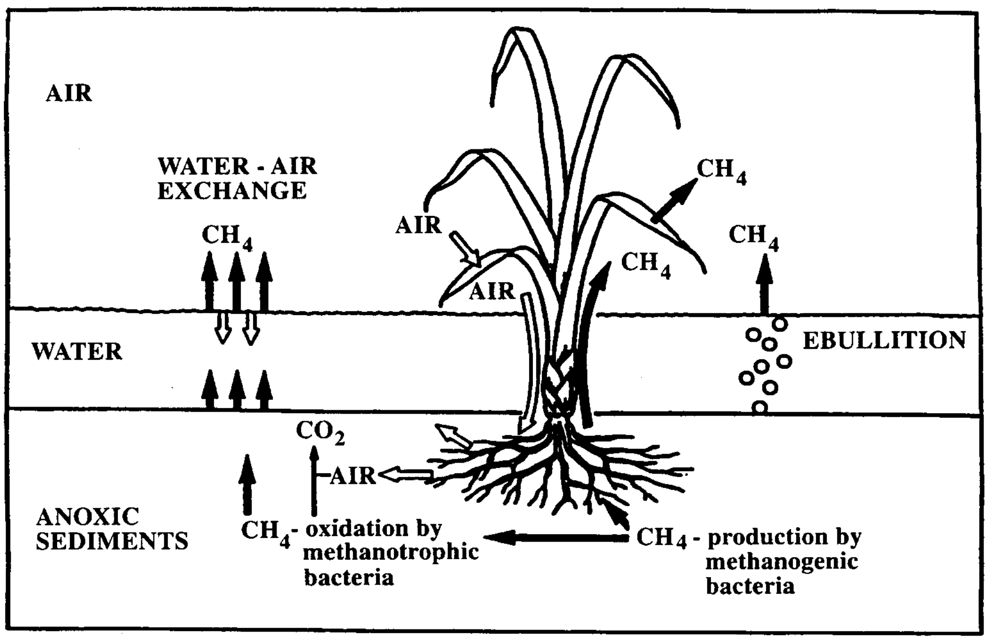
[2] Eight states grow rice: Arkansas, California, Florida, Louisiana, Mississippi, Missouri, Oklahoma, and Texas.

[3] Note that all rice-growing areas in the United States are classified as continually flooded; none are upland or deepwater.

with more typical, shallow flooding depths. Also, some flooded fields are drained periodically during the growing season, either intentionally or accidentally. If water is drained and soils are allowed to dry sufficiently, CH_4 emissions decrease or stop entirely. This is due to soil aeration, which not only causes existing soil CH_4 to oxidize but also inhibits further CH_4 production in the soils.

Other factors that influence CH_4 emissions from flooded rice fields include soil temperature, soil type, fertilization practices, rice cultivar selection, and other cultivation practices (e.g., tillage, seeding, and weeding practices). Many studies have found, for example, that CH_4 emissions increase as soil temperature increases. Several studies have indicated that some types of nitrogen fertilizer inhibit CH_4 generation, while organic fertilizers enhance CH_4 emissions. However, while it is generally acknowledged that these factors influence CH_4 emissions, the extent of the influence of these factors individually or in combination has not been well quantified. Thus, the method for estimating emissions is based on a range of measured emissions per unit area of flooded rice field per season.

Figure 9.2-1 Methane Emissions from Rice Cultivation



Source: Schütz, et al. (1988)

Table 9.2-1: Greenhouse Gas Emissions and Sinks from the Agricultural and Forest Sectors

A check indicates emissions or sinks may be significant

Activity	Associated Greenhouse Gas Emissions and Sinks and Chapter where these Emissions or Sinks are Addressed					
	CO_2	Chapter	CH_4	Chapter	N_2O	Chapter
Energy (Farm Equipment)	✓	1	✓	3	✓	3
Animal Production: Enteric Fermentation			✓	7		
Animal Production: Manure Management						
Solid Storage			✓	8	✓	8
Drylot			✓	8	✓	8
Deep Pit Stacks			✓	8	✓	8
Litter			✓	8	✓	8
Liquids/Slurry			✓	8	✓	8
Anaerobic Lagoon			✓	8	✓	8
Pit Storage			✓	8	✓	8
Periodic land application of solids from above management practices					✓	10
Pasture/Range (deposited on soil)			✓	8	✓	10
Paddock (deposited on soil)			✓	8	✓	10
Daily Spread (applied to soil)			✓	8	✓	10
Animal Production: Nitrogen Excretion (indirect emissions)					✓	10
Cropping Practices						
Rice Cultivation			✓	9		
Commercial Synthetic Fertilizer Application					✓	10
Commercial Organic Fertilizer Application					✓	10
Incorporation of Crop Residues into the Soil					✓	10
Production of Nitrogen-fixing Crops					✓	10
Liming of Soils	✓	12				
Cultivation of High Organic Content Soils (histosols)	✓	10			✓	10
Cultivation of Mineral Soils	✓	Not included[a]				
Changes in Agricultural Management Practices (e.g., tillage, erosion control)	✓	Not included[a]				
Forest and Land Use Change						
Forest and Grassland Conversion	✓	12				
Abandonment of Managed Lands	✓	12				
Changes in Forests and Woody Biomass Stocks	✓	12				
Agricultural Residue Burning			✓	11	✓	11

[a] Emissions may be significant, but methods for estimating greenhouse gas emissions from these sources are not included in the EIIP chapters.

3

OVERVIEW OF AVAILABLE METHODS

Methane emissions from rice cultivation can be estimated based on the acreage of rice grown (i.e., flooded) in a state[4] and emission factors for the amount of methane emitted per flooding season.

Mean seasonal emission factors are used to calculate methane emissions from the primary and ratoon[5] crops. Additionally, low and high values of seasonal methane emission factors for the primary and ratoon crops are used to calculate the estimated range of emissions. The ranges reflect the uncertainty in measured seasonal emissions.

The methodology described in this chapter is used to estimate national emissions from this source for the U.S. Inventory of Greenhouse Gas Emissions (U.S. EPA 2004). As in the U.S. Inventory, this methodology follows the *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC/UNEP/OECD/IEA 1997) but incorporates a United States-specific emission factor. Consistent with the IPCC *Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories* (IPCC 2000), the methodology estimates emissions from primary and ratoon crops separately. The United States began using this methodology for the 1990-2000 national inventory. Previously, emissions estimates were based on rice acreage, average number of days flooded, and daily emission factors. The new methodology simplifies the calculations to a function of harvested rice area and seasonal emission factors.

[4] Wild rice is not included in these calculations because it is considered a grain, not a rice variety.

[5] The climatic conditions of southwest Louisiana, Texas, and Florida allow for a second or "ratoon" rice crop in those areas. This second crop of rice is produced from regrowth on the stubble after the first crop has been harvested. Emission estimates for these states should reflect emissions from the ratoon crop.

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Preferred Method for Estimating Emissions

To estimate methane (CH_4) emissions from rice cultivation, the following steps are required: (1) obtain required data on the area of rice fields flooded, for primary and ratoon crops;[6] (2) calculate CH_4 emissions; and (3) convert units to metric tons of carbon equivalent (MTCE). These steps are outlined in detail below and can be followed using the Agriculture Module of the State Inventory Tool.

Step (1): Obtain Required Data

- *Required Data.* The information needed to calculate methane emissions from flooded rice fields is the total area harvested for the study year in hectares, separately accounting for primary and ratoon crops, where applicable (Texas, Louisiana, and Florida).[7]

- *Data Sources.* State agencies responsible for overseeing the agricultural sector (such as agricultural extension agencies at state universities) should be consulted. Agricultural statisticians in each of the eight states that produces rice can be contacted to determine state water management, acreage, and cropping practices. Alternatively, harvested rice area for the major rice producing states, except Florida and Oklahoma,[8] can be found in the U.S. Department of Agriculture's annual *Crop Production* report (USDA 2003). The three previous years' data are presented in each annual report; data for 1997 and earlier are presented in USDA *Field Crops Final Estimates* reports, which are published approximately every five years. These annual and historical reports can be accessed from the Web at http://usda.mannlib.cornell.edu. Areas of primary and ratoon crop production are also available by state in the Agriculture Module of the State Inventory Tool.

Rice fields for the ratoon crop typically remain flooded for a shorter period of time than for the first crop. Recent studies indicate, however, that the CH_4 emission rate of the ratoon crop may be significantly higher than that of the primary crop. The rice straw produced during the first harvest has been shown to dramatically increase methane emissions during the ratoon cropping season (Lindau & Bollich, 1993). The higher emission rate of the ratoon crop supports the use of an emission factor specific to the ratoon rice crop.

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[6] A ratoon rice crop is a second crop of rice grown from the stubble after harvest of the primary or first crop.

[7] If data are in acres, convert to hectares by dividing by 2.471 (the number of acres per hectare).

[8] The USDA does not report data for Florida or Oklahoma; this information must be obtained through a state agricultural extension agent.

Total ratoon cropping area can vary annually and is reported as a percentage of the primary crop area. Table 9.4-1 provides default percentages of primary rice area used for ratoon cropping by state (Guethle 2003, Kirstein 2003, Klosterboer 2003, Lee 2003, Linscombe 2003, Mutters 2003, Street 2003, Wilson 2003). Local rice experts should be consulted for more accurate estimates of ratooned areas.

Table 9.4-1: Percent of Rice Areas Ratooned

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
AR	0	0	0	0	0	0	0	0	*	*	0	0	0
CA	0	0	0	0	0	0	0	0	0	0	0	0	0
FL	50	50	50	50	50	50	50	50	50	65	41	60	54
LA	30	30	30	30	30	30	30	30	30	30	40	30	15
MS	0	0	0	0	0	0	0	0	0	0	0	0	0
MO	0	0	0	0	0	0	0	0	0	0	0	0	0
OK	0	0	0	0	0	0	0	0	0	0	0	0	0
TX	40	40	40	40	40	40	40	40	40	40	50	40	37

* = 500 acres of rice were ratooned experimentally in Arkansas in 1998 and 1999.

Example: In 2000 in Louisiana the primary area harvested was 480,000 acres of rice. The area used for the ratoon crop in Louisiana is 40 percent of the primary area. Therefore, the area flooded for the ratoon crop season may be calculated as follows:

480,000 acres x 0.40 = 192,000 acres for the ratoon crop

Convert from acres to hectares:

480,000 acres / 2.471 acre/ha = **194,253 ha** primary crop
192,000 acres / 2.471 acre/ha = **77,701 ha** ratoon crop

Step (2): Estimate Methane Emissions

Default CH_4 emission factors for primary and ratoon crops were obtained from field studies performed in California (Bossio et al., 1999; Cicerone et al., 1992); Texas (Sass et al., 1990, 1991a, 1991b, 1992); and Louisiana (Lindau et al., 1995; Lindau and Bollich, 1993). A mean emission factor (210 kg CH_4/ha-season for primary and 780 kg CH_4/ha-season for ratoon), determined from the experimental results, is used to estimate emissions.[9] Minimum and maximum emission rates measured in these studies – 22 kg CH_4/ha-season to 479 kg CH_4/ha-season (primary) and 481 kg CH_4/ha-season to 1,490 kg CH_4/ha-season (ratoon) – can be applied to the flooded areas in each state to determine a range of emissions (see Table 9.4-2). Since these

[9] The seasonal emission factors for the primary crop were determined by taking the average of the "primary, synthetic nitrogen (N) fertilizer and organic fertilizer" group's emissions. The seasonal emission factor for the ratoon crop was determined by taking the average of the "ratoon, synthetic N fertilizer" group's emissions. Certain measurements from these studies were excluded when determining the emission coefficient range due to accidental drainage of floodwater, and unusually high/low results as compared to other flux measurements in the United States, as well as in Europe and Asia (see IPCC/UNEP, OECD, IEA 1997).

measurements were taken in rice growing areas of the United States, they represent rice soil temperatures and water and fertilizer management practices typical of the United States.

Table 9.4-2: Default Methane Emission Factors
(kg CH_4/ha-season)

	Primary	Ratoon
Mean[10]	210	780
Low	22	481
High	479	1490

For the primary crop estimate, multiply the number of flooded primary hectares on which rice was grown by the mean estimate of the emission factor (210 kg CH_4/ha-season).

Primary Estimate: CH_4 Emissions (primary) (kg CH_4) = Primary Rice Area (ha) x 210 kg CH_4/ha-season

For the ratoon crop estimate (where applicable), multiply the number of flooded ratoon hectares on which rice was grown by the mean estimate of the emission factor (780 kg CH_4/ha-season).

Ratoon Estimate: CH_4 Emissions (ratoon) (kg CH_4) = Ratoon Rice Area (ha) x 780 kg CH_4/ha-season

Sum the results (primary + ratoon) to obtain total state CH_4 emissions from rice cultivation in kg.

Step (3): Convert Units to Metric Tons of Carbon Equivalent

Divide the results by 1,000 to obtain CH_4 emissions in metric tons. Then multiply by 12/44 (the ratio of the molecular weight of carbon to the molecular weight of CO_2) and by 21 (the Global Warming Potential of CH_4) to obtain CH_4 emissions in MTCE.

Example: Louisiana's CH_4 emissions from flooded rice fields in 2000 are calculated as follows:

(a)

	Flooded Area		Emissions Coefficient		CH_4 Emissions
Primary	194,253 ha	x	210 kg CH_4/ha-season	=	40,793,130 kg CH_4/yr
Ratoon	77,701 ha	x	780 kg CH_4/ha-season	=	60,606,780 kg CH_4/yr

(b) 40,793,130 + 60,606,780 kg CH_4/yr = 101,399,910 kg CH_4/yr

101,399,910 kg CH4/yr ÷ 1000 kg/metric ton = 101,400 MT CH_4

101,400 MT CH_4 x 12/44 x 21 = **580,745 MTCE**

To estimate a range of emissions from rice cultivation in state, repeat the steps above twice—once using the low emission factors and once using the high emission factors. The mean values

[10] The mean emission factors are not the average of the high and low values, but rather the average of the emission factors presented in the experimental studies.

are used in reporting emissions, while the estimated range of emissions demonstrates the range of uncertainty.

5

ALTERNATIVE METHODS FOR ESTIMATING EMISSIONS

There are no alternative methods for estimating state-level emissions from rice cultivation at this time.

6

UNCERTAINTY SUMMARY

Methane (CH_4) emissions from rice fields are affected by many factors. Field experiments have clearly identified several of these factors, including (1) water levels throughout the growing season; (2) temperature; (3) fertilizer application; (4) soil type; (5) the cultivated variety (cultivar) of rice grown; and (6) agricultural practices such as direct seeding or transplanting. Data show that higher temperature, continuously flooded fields, some types of organic fertilizers, and certain cultivars lead to higher emissions. The methodology followed in this chapter includes emissions from both primary and ratoon rice crops. Uncertainties exist in both the emission factors and activity data used to derive the estimates for both cropping seasons.

The greatest uncertainty in calculating CH_4 emissions from flooded rice fields relates to the emission factors. Seasonal emissions, as calculated from U.S. field measurements, vary by over one order of magnitude. This variability can be attributed to differences in the way rice is cultivated by different farmers. Such differences often vary by region and include type, quantity, and application method of fertilizer; cultivar type; and varying soil and climatic conditions. This methodology accounts for some of the variability by separating calculations for primary and ratooned areas. However, significant variability can exist even within measured emissions from one cropping season or a certain type of rice cultivation management.

There is also uncertainty surrounding the activity data concerning the area planted each season. Uncertainty associated with ratooned areas can be high, as these data are not collected on a regular basis. Data on ratooned areas are often determined by expert judgment and thus subject to greater uncertainty than primary areas quantified by farm survey or measurement. (U.S. EPA 2004)

7

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