VOLUME VIII: CHAPTER 11

METHODS FOR ESTIMATING GREENHOUSE GAS EMISSIONS FROM FIELD BURNING OF AGRICULTURAL RESIDUES

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Volume VIII, Chapter 11, Field Burning of Agricultural Residues

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CONTENTS

TABLES

Page

1

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, nitrous oxide, carbon monoxide, and nitrogen oxides emissions from the burning of agricultural residues. 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 U.S. 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, nitrous oxide, carbon monoxide, and nitrogen oxides emissions from the burning of agricultural residues. Section 4 presents the preferred estimation method. Section 5 presents an alternative estimation technique designed for use by California. 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.

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[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

Agricultural production results in large quantities of crop wastes. In some parts of the United States, these residues are burned in the field to clear remaining straw and stubble after harvest, and to prepare the field for the next cropping cycle. Other approaches to managing these wastes include plowing them back into the field, composting or landfilling them, or collecting them for use as a biomass fuel or as supplemental feed.

This chapter addresses field burning of agricultural crop wastes. When crop residues are burned, a number of greenhouse gases are released, including carbon dioxide, methane, nitrous oxide, carbon monoxide, and nitrogen oxides.

This chapter provides a methodology for estimating the methane and nitrous oxide emissions that result from combustion of crop residues. This version of the guidance has been expanded to include a methodology for estimating emissions of carbon monoxide and nitrogen oxides as well. However, because these emissions have an indirect effect on radiative forcing and therefore have not been assigned global warming potential values, their impact cannot be converted to tons of carbon equivalent and included in the state's totals. In accordance with international greenhouse gas accounting guidelines, this chapter does not include a methodology for estimating carbon dioxide emissions from crop residue burning. This is because the carbon released as carbon dioxide during burning had been taken up from carbon dioxide in the atmosphere during the growing season, thus resulting in no net emissions.

This chapter addresses emissions from burning residues of seven crops for which burning of crop wastes is significant in the United States—barley, corn, peanuts, rice, soybeans, sugarcane, and wheat. Field burning may also result in enhanced emissions of nitrous oxide and nitrogen oxides many days after burning (Anderson et al. 1988; Levine et al. 1988), but this process is highly uncertain and is not addressed in this chapter.

This source category accounts for only some of the many agricultural and forestry activities that emit greenhouse gases. Table 11.2-1 summarizes the agricultural and forestry activities associated with emissions of carbon dioxide, methane, and nitrous oxide, and provides a roadmap indicating the chapter in which each activity is addressed.

Table 11.2-1: 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

The methodology for estimating greenhouse gas emissions from field burning of agricultural residues is based on: (1) the amounts of carbon and nitrogen in the crop residue combusted; (2) the emission ratio of methane to carbon released in combustion (as measured in the smoke of biomass fires); and (3) the emission ratio of nitrous oxide to nitrogen released in combustion. To estimate emissions of methane and nitrous oxide from burning of agricultural wastes, the following steps are necessary: (1) obtain the required data; (2) estimate the total amount of carbon and nitrogen released; and (3) estimate emissions of methane, nitrous oxide, carbon monoxide, and nitrogen oxides based on the amount of carbon and nitrogen released.

The methods described here are taken from the report by the Intergovernmental Panel on Climate Change (IPCC) entitled *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC/UNEP/OCED/IEA 1997). These methods are used in the *Inventory of U.S. Greenhouse Gas Emissions and Sinks* (U.S. EPA 2004).

4

PREFERRED METHOD FOR ESTIMATING EMISSIONS

The preferred method for estimating emissions of methane (CH_4) and nitrous oxide (N_2O) from field burning of agricultural residues consists of the following seven steps: (1) obtain required data; (2) calculate the amount of dry matter burned; (3) calculate total carbon (C) released; (4) estimate emissions of CH_4; (5) estimate nitrogen (N) content of the dry matter; (6) estimate emissions of N_2O; and (7) convert to units of metric tons of carbon equivalent (MTCE). These steps can be performed manually or electronically with the Agriculture Module of the State Inventory Tool (hereafter referred to as the State Inventory Tool). Two additional steps at the end of the methodology describe how to estimate emissions of carbon monoxide (CO) and (NO_x), two indirect greenhouse gases.

Step (1): Obtain Required Data on Crop Production

- *Required Data*. The information needed to estimate greenhouse gas emissions from burning of agricultural wastes is the annual production of barley, corn, peanuts, rice, soybeans, sugarcane, and wheat.
- *Data Sources*. State agricultural agencies should be consulted first, as they have the most accurate local data. Alternatively, crop production data are published annually by USDA; the most recent publication is *Crop Production 2002 Summary* (USDA 2003), and these data are incorporated in the State Inventory Tool.

  Annual crop production should be reported in metric tons. The State Inventory Tool provides a conversion to metric tons from bushels of barley, corn, soybeans, and wheat; pounds of peanuts; hundred count of rice; and tons of sugarcane. Conversion factors for these units and crops are provided below in Table 11.4-1 and followed by an example calculation.

Table 11.4-1: Common Unit Conversions

Crop Type	Common Units for Reporting Data	Conversion Factor from Common Unit to Metric Tons
Barley	Bushels	0.025
Corn	Bushels	0.025
Peanuts	Pounds	0.00045
Rice	Hundred Count (cwt)	45.4
Soybeans	Bushels	0.027
Sugarcane	Short Tons	0.9072
Wheat	Bushels	0.027

Example:	According to the USDA's report *Crop Production 2000 Summary*, total U.S. wheat production in 2000 was 2,223,440,000 bushels. 2,223,440,000 bushels x 0.027 metric tons/bushel = **60,032,880 metric tons**

Step (2): Calculate the Amount of Dry Matter Burned

For each crop, calculate the amount of dry matter burned using the default values provided in Table 11.4-2. Multiply crop production by the residue/crop ratio, the proportion of residue burned, the proportion of dry matter, burning efficiency, and combustion efficiency to determine mass of dry matter combusted.

Amount of Dry Matter Burned (metric tons) **=** *Annual Crop Production (metric tons) x Residue/Crop Ratio x Proportion of Crop Produced in Fields where Residue is Burned (%) x Dry Matter Content of the Residue (%) x Burning Efficiency (%) x Combustion Efficiency (%)*

Burning efficiency is defined as the fraction of dry biomass exposed to burning that actually burns. Combustion efficiency is defined as the fraction of C in the fire that is released to the atmosphere.[2]

Example:	The quantity of wheat residue burned in 2000 is calculated as follows: 60,032,880 metric tons of wheat x 1.3 metric tons residue/metric tons crop product x 0.03 portion of crop produced in fields where residue is burned x 0.93 dry matter content x 0.93 burning efficiency x 0.88 combustion efficiency = **1,781,978 metric tons dry matter**

Step (3) Calculate Total Carbon Released

For each crop, take the amount of dry matter burned (estimated in Step 2) and multiply it by the fraction of C in the residue to estimate the total amount of C released. Ratios of C to dry matter for selected crop residues are presented in Table 11.4-3.

Total C Released (metric tons) = Dry Matter Burned (metric tons) x C Content of the Residue (metric tons C/metric tons dry matter)

Example:	The total amount of C released from burning of U.S. wheat residue in 2000 is calculated as follows: 1,781,978 metric tons dry matter x 0.4428 (metric tons C/metric tons dry matter) = **789,060 metric tons C**

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[2] In the methodology recommended by the IPCC, the “burning efficiency” is assumed to be accounted for in the factor for “fraction of residues burned.” However, the number used here to estimate the “fraction of residues burned” does not account for the fraction of exposed residue that does not burn. Therefore, a “burning efficiency factor” is added to the calculations.

Table 11.4-2: Crop-Specific Ratio, Proportion, and Efficiency Values

Crop Type	Residue/ Crop Ratio	Proportion of Residue Burned	Proportion of Dry Matter	Burning Efficiency	Combustion Efficiency
Barley	1.2	0.03	0.93	0.93	0.88
Corn	1.0	0.03	0.91	0.93	0.88
Peanuts	1.0	0.03	0.86	0.93	0.88
Rice	1.4	Variable[a]	0.91	0.93	0.88
Soybeans	2.1	0.03	0.87	0.93	0.88
Sugarcane	0.8	0.03	0.62	0.93	0.88
Wheat	1.3	0.03	0.93	0.93	0.88

[a] Consult a state agricultural extension agent for an accurate value. State-specific default values are available in the State Inventory Tool.

Sources: Residual crop ratios were obtained from Strehler and Stützle (1987) and University of California (1997). Fraction residue burned is an assumption based on State inventory data: ILENR 1993; Oregon Dept. of Energy 1995; Noller 1996; Wisconsin Department of Natural Resources 1993; and Cibrowski 1996. Dry matter fractions from Turn et al. 1997, with the exception of soybeans (from Strehler and Stützle 1987) and peanuts (from Ketzis 1994).

Table 11.4-3: Carbon/Nitrogen Contents and Emission Ratios

Crop Type	Carbon Content (metric tons C/ metric tons dm)	Nitrogen Content (metric tons N/ metric tons dm)	CH_4-C Emission Ratio	N_2O-N Emission Ratio	CO-C Emission Ratio	NOx-N Emission Ratio
Barley	0.4485	0.0077	0.005	0.007	0.060	0.121
Corn	0.4478	0.0058	0.005	0.007	0.060	0.121
Peanuts	0.4500	0.0106	0.005	0.007	0.060	0.121
Rice	0.3806	0.0072	0.005	0.007	0.060	0.121
Soybeans	0.4500	0.0230	0.005	0.007	0.060	0.121
Sugarcane	0.4235	0.0040	0.005	0.007	0.060	0.121
Wheat	0.4428	0.0062	0.005	0.007	0.060	0.121

Sources: Carbon and nitrogen contents from Turn et al. 1997, except soybeans and peanuts whose C contents are IPCC defaults, and N contents come from Barnard and Kristoferson 1985 and Ketzis 1994, respectively

Step (4): Estimate Emissions of Methane

For each crop, multiply the amount of C released by the emission ratio of CH_4 relative to total C (as listed in Table 11.4-3) to determine emissions of CH_4 in units of carbon (CH_4-C). Then convert emissions of CH_4-C to full molecular weights for CH_4 emissions by multiplying by the mass ratio of CH_4 to C (16/12).

CH_4 Emissions (metric tons CH_4) = Amount Released (metric tons C) x (0.005 CH_4-C/C) x (16/12)

Example:	CH_4 emissions from burning of residue from U.S. wheat production in 2000 are calculated as follows: 789,060 metric tons C x 0.005 CH_4-C/C x 16/12 = **5,260 metric tons CH_4**

Step (5): Estimate Nitrogen Content of the Dry Matter

For each crop, multiply the amount of dry matter burned by the ratio of N to dry matter in the crop residues. Ratios of N to dry matter for selected crop residues are presented in Table 11.4-3.

Total N Released (metric tons N) = Dry Matter Burned (metric tons) x N Content (metric tons N/metric tons dry matter)

Example:	The total amount of N released from U.S. wheat residue in 2000 is calculated as follows: 1,781,978 metric tons dm x 0.0062 metric tons N/metric tons dm = **11,048 metric tons N**

Step (6): Estimate Emissions of Nitrous Oxide

For each crop, multiply the amount of N released by the N_2O-N emission ratio (as listed in Table 11.4-3) to obtain emissions in units of N_2O-N. Then convert these emissions to full molecular weight of N_2O by multiplying by (44/28), the mass ratio of N_2O to N.

N_2O Emissions (metric tons N_2O) = Amount of N Released (metric tons) x (0.007 N_2O-N/N) x (44/28)

Example:	N_2O emissions from burning of residue from U.S. wheat production in 2000 are calculated as follows: 11,048 metric tons N x 0.007 N_2O-N/N x (44/28) = **122 metric tons N_2O**

Step (7): Convert to Metric Tons of Carbon Equivalent

To estimate total direct emissions of CH_4 and N_2O from agricultural residue burning, complete the following steps:

- For each crop, convert the emissions from metric tons of gas to MTCE. Convert by multiplying by the Global Warming Potential (GWP) for each gas. GWP for CH_4 is 21; the GWP for N_2O is 310. Then multiply by the mass ratio of C to CO_2.

- For each gas, sum across all crop types to produce total emissions from burning of crop residues.

Example:	Emissions of CH_4 and N_2O from burning of residue from U.S. wheat production in 2000 are converted to MTCE as follows:	
	CH_4 Emissions:	5,260 metric tons CH_4 x 21 x (12/44) = **30,125 MTCE**
	N_2O Emissions:	122 metric tons N_2O x 310 x (12/44) = **10,315 MTCE**

Additional Steps

To estimate emissions of CO and NO_x, complete the following additional steps:

- For each crop, take the amount of C released (calculated in Step 3) and multiply it by the CO-C emission ratio (see Table 11.4-3). Then convert to full molecular weight using the CO conversion factor (28/12).
- For each crop, take the amount of N released (calculated in Step 5) and multiply it by the NO_x-N emission ratio (see Table 11.4-3). Then convert to full molecular weight using the NO_x conversion factor (30/14).

Example	Emissions of CO and NO_x from burning of residue from U.S. wheat production in 2000 are calculated as follows:
	CO Emissions: 789,060 metric tons C x 0.060 CO-C/C x (28/12) = **110,468 metric tons CO**
	NO_x Emissions: 11,048 metric tons N x 0.121 NO_x-N/N x (30/14) = **2,865 metric tons NO_x**

5

ALTERNATIVE METHODS FOR ESTIMATING EMISSIONS

An alternate method for estimating emissions from agricultural residue burning has been established for the state of California by B.M. Jenkins and fellow researchers at the University of California at Davis (Jenkins and Turn, 1994 Jenkins et al. 1992). This methodology uses California-specific parameters for the six crops that comprise the majority of burned agricultural (crop) biomass in the state—almonds, walnuts, wheat, barley, corn, and rice.

Emissions from agricultural burning of each crop are estimated by multiplying the crop's production area by the residue yield, fraction burned, and emission factors for each type of crop and greenhouse gas.

Emissions = Production Area x Residue Yield x Fraction Burned x Emission Factor

Emissions are then summed across the six crop types.

Crop production data can be taken from state agricultural agencies or the annual USDA report *Crop Production Summary* (USDA 2001), as noted in Section 4. Crop-specific parameters obtained from the *Inventory of California Greenhouse Gas Emissions and Sinks: 1990-1999* can be found below in Table 11.5-1.

Table 11.5-1: Crop-Specific California Parameters

	Almonds	**Walnuts**	**Wheat**	**Barley**	**Corn**	**Rice**
Burn Fraction (%)	84	95	11	7	3	99
Residue Yield (ton/hectare dry basis)	1.89	1.46	3.66	2.51	9.06	6.75
CH_4 Emission Factor (% dry crop mass)	0.12	0.16	0.18	0.25	0.18	0.08
N_2O Emission Factor (% dry crop mass)	0.02	0.02	0.01	0.02	0.01	0.02

Source: Jenkins et al. 1992, Jenkins and Turn 1994, as cited in the Inventory of California Greenhouse Gas Emissions and Sinks: 1990-1999

No alternative methods for this source are available for other states at this time.

6

UNCERTAINTY SUMMARY

The methodologies presented in this chapter account for non-carbon dioxide emissions, including methane, nitrous oxide, carbon monoxide, and nitrogen oxides, from field burning of agricultural residues. As in the *Inventory of U.S. Greenhouse Gas Emissions and Sinks*, major sources of uncertainty in this sector are the quantity of residue burned per year and the variability in states' burning practices (U.S. EPA 2004). Both the emission factors and activity data introduce uncertain elements into the calculations.

The gas emission ratios have a relatively high level of uncertainty as they are region-specific (not country- or state-specific). Low level uncertainty also surrounds residue dry matter content, burning efficiency, and combustion efficiency values used (U.S. EPA 2004).

Since there is no national or state-level collection of data on the fraction of crop residue burned, and burning practices vary by state and crop, these data are highly uncertain. Additional sources of uncertainty include crop production data and residue to crop production ratios at low levels (U.S. EPA 2004).

7

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