

February 4, 2009

**TECHNICAL SUPPORT DOCUMENT FOR
BIOLOGIC PROCESS SOURCES EXCLUDED
FROM THIS RULE**

Office of Air and Radiation
U.S. Environmental Protection Agency

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Introduction

The proposed rule does not require reporting of GHG emissions from enteric fermentation, rice cultivation, field burning of agricultural residues, composting, agricultural soils (including C sequestration and N₂O emissions), settlements (including N₂O emissions), forestland (including CH₄ and N₂O emissions) or other land uses and land-use changes, such as emissions associated with deforestation, and carbon storage in living biomass or harvested wood products. The challenges to including these source categories in the rule are that available methods to estimate facility-level emissions for these sources yield uncertain results, and that these sources are characterized by a large number of small emitters. In light of these challenges, we have determined that it is impractical to require entity-level reporting of emissions from these sources in the proposed rule for the reasons explained below.

For more information on these sources and sinks of greenhouse gases, please see page 6 of this TSD for enteric fermentation, page 10 for rice cultivation, page 13 for field burning of agricultural residues, page 16 for composting, page 19 for agricultural C sequestration, page 23 for agricultural N₂O emissions (including fertilizer use), page 26 for settlement N₂O emissions (including fertilizer use), page 28 for forestland CH₄ and N₂O emissions (including fires and fertilizer use), and page 33 for other land use, and land-use change, and forestry emissions and sinks.

Biological Process Excluded Sources Summary

Total Emissions

EPA reports on the greenhouse gas emissions and sinks associated with the biological process sources excluded from this rule in the *Inventory of U.S. Greenhouse Gas Emissions and Sinks*. In the agriculture sector, the U.S. GHG Inventory estimates that agricultural soil management contributed emissions of 265 MMTCO₂e and enteric fermentation contributed emissions of 126 MMTCO₂e in 2006. Rice cultivation, agricultural field burning, and composting contributed emissions of 5.9, 1.2, and 3.3 MMTCO₂e, respectively, in 2006. Total carbon fluxes for U.S. forestlands and other land uses and land-use changes were also reported in the U.S. GHG Inventory, rather than specific emissions from deforestation. Land use, land-use change, and forestry activities in 2006 resulted in a net C sequestration of 883.7 MMTCO₂e.

Review of existing relevant reporting programs/ methodologies

Several protocols and programs contain methods for estimating greenhouse gases from these sources, including the 2006 IPCC GL and the U.S. GHG Inventory. These methods are used to estimate national-level emissions and sinks.

Monitoring Methods

For these sources, there are no direct greenhouse gas emission measurement methods available except for research methods that are prohibitively expensive and require sophisticated equipment. Instead, limited modeling-based methods have been developed for voluntary GHG

reporting protocols, which use general emission factors, or large-scale models that are used for comprehensive national-level emissions estimates.

To calculate the emissions resulting from these sources at a reporting entity-level using emission factor or carbon stock change approaches, it would be necessary for landowners to report on a number of parameters such as management practices and a variety of data inputs. While some input data can be collected with reasonable certainty, the emissions estimates would have a high degree of uncertainty because the factors available for individual reporters do not reflect the variety of conditions that need to be considered for accurate estimates. At the scale of individual reporters, these estimates can be complex and costly to generate.

Without accurate facility-level emissions factors and the ability to accurately measure all facility-level calculation variables, estimates of national-level emissions from these sources are more suitably calculated on a broad regional basis using models and data available from national databases. While a systematic measurement program of these sources could improve understanding of the environmental factors and management practices that influence emissions, this type of measurement program would be very difficult to implement through a landowner-based reporting program due to the difficulty and expense in establishing and maintaining rigorous measurements over time.

Threshold Analysis

Despite these issues, threshold analyses were conducted for several of these sources as part of their consideration for inclusion in this rule. The resulting analyses showed that for most of these sources no facilities would meet thresholds consistent with those proposed in this rule.

Enteric Fermentation

Ruminant agriculture (cattle –beef and dairy, sheep, goats and buffalo) is the primary source of enteric CH₄. Since feed quality and quantity affects enteric CH₄ emissions, approaches for estimating CH₄ emissions focus on gross energy intake from feed and CH₄ yield (portion of gross energy that is converted to CH₄ in the rumen). For example, dairy cows in California on a total mixed ration (a blend of all feedstuffs provided to dairy cows) diet emit between 100 to 160 kg CH₄/cow/yr (2,100 to 3,360 kg CO₂e/cow/yr). At these emission rates, only the largest facilities (over 3,000-5,000 cows) would have to report enteric emissions under a mandatory reporting threshold of 10,000 mtCO₂e/yr.

Monitoring Emissions

In general, there are two approaches for monitoring enteric CH₄ emissions: direct measurement and modeling. Since direct measurement using tracers is prohibitively expensive and overly burdensome for reporters, modeling enteric emissions with emission factors is the only reasonable alternative. The *2006 IPCC Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories* Volume 4, Chapter 10, Equation 10.21 provides the following emission factor equations most suitable for monitoring:

$$EF_{\text{Enteric-CH}_4} = [\text{GE} \times \text{Ym}] * 365 / [55.65 \text{ MJ/kg CH}_4]$$

Where:

EF _{Enteric-CH₄}	= emission factor (kg CH ₄ /head/year)
GE	= gross energy intake (MJ/head/day)
Ym	= CH ₄ conversion rate which is the fraction of gross energy in feed converted to CH ₄ (percent)

Most livestock producers have a good understanding of their diet regimes. However, they would need to calculate the gross energy intake based on the amount and type of feed.

Information to be Collected

The following information would need to be collected to monitor emissions using the IPCC methodology: number of animals by livestock type on farm (track seasonal changes), gross energy intake (derived from diet) by livestock type, and estimate of methane conversion rate (could be estimated based on feed efficiency, but requires chamber measurements to estimate accurately).

Uncertainty

In addition to the uncertainty in estimating gross energy intake, a large source of uncertainty in estimating enteric emissions is due to the large variability in the CH₄ conversion rates (Ym). Tables 10.12 and 10.13 from Volume 4, Chapter 10 of *2006 IPCC Guidelines for National Greenhouse Gas Inventories* provide ranges of Ym based on livestock category. For example, feedlot cattle have Ym range of 3 ±1%, indicating that using the 3% value can result in overestimation by 50% or an underestimation up to 33%. Research by Benchaar et al (1998) has shown an even greater range of Ym values from less than 3% to

greater than 10%. Although the use of feed additives (e.g., ionophores, probiotics, propionate precursors, and growth hormones), which can improve feed efficiency by suppressing methanogenesis, is becoming more widespread, quantification of their effectiveness in reducing enteric emissions is not well understood.

Reporters and Thresholds

Individual livestock operations would be the reporters as they have information on their livestock numbers and general feeding regimes. According to the 2002 NASS Agricultural Census there are over 1 million farms with cattle and approximately 2,450 of these farms have over 2,500 cattle. Tables 1 and 2 present the number of farms by size class for beef and dairy cattle, respectively.

Table 1. Beef Farm Sizes

Beef Farm Size (2002)	Number of Farms	% of Total Population
Less than 1,000 head	918,184	70%
1,000-2,499	5,728	8.6%
2,500-4,999 head	1553	6.0%
5,000 – 9,999 head	655	8.5%
Greater than 10,000 head	250	6.5%

Note: Given the lack of data on farms larger than 10,000 head and the observed decrease in number of beef farms with increasing size, we estimate that there are less than 96 farms with greater than 20,000 head of beef cattle. There are a few very large beef feedlots (e.g., A ranch in California has over 100,000 head of cattle).

Table 2. Large Dairy Farms Size Distribution

Dairy Farm Size (2002)	Number of Farms	% of Total Population
1,000-1,999 cows	795	13%
2,000-2,999 cows	249	6.8%
3,000-3,999 cows	115	4.4%
4,000-4,999 cows	48	2.4%
5,000-9,999 cows	39	3.2%
10,000 or more	8	1.1%

Table 3 presents the size thresholds for beef and dairy livestock operations to exceed the 3 reporting thresholds. Given, the large amount of uncertainty in estimating enteric emissions, two sets of calculations are provided with average and high end emission factors. The average emission factors were derived dividing total enteric emissions (Table A-157 EPA 2008) by population (Table A-159 EPA 2008). The high factors were estimated at 50% greater than the average emission factors.

Table 3. Threshold Populations for Beef and Dairy Farms

	Threshold Levels (mtCO ₂ e)			
	1,000	10,000	25,000	100,000
	Total number of head to meet threshold			
BEEF FARM: AVERAGE (Emission factor: 1,016 kg CO ₂ e/head/yr)	984	9,843	24,606	98,425
BEEF FARM: HIGH (Average plus 50%: 1,524 kg CO ₂ e/head/yr)	656	6,562	16,404	65,617
DAIRY FARM (Average emission factor: 2,305kg CO ₂ e/head/yr)	434	4,338	10,846	43,384
DAIRY FARM (Average plus 50%: 3,458 kg CO ₂ e/head/yr)	289	2,892	7,230	28,918

Note: Estimates presented have not been adjusted to account for significant figures.

Table 4 presents the maximum number of potential reporters by threshold level. The number of reporters was estimated based on the number of livestock needed to exceed each threshold level (Table 3) and a rough estimate of the number of livestock facilities that have the corresponding number of cattle (see note on interpolation assumptions within each size category in Tables 1 and 2.

Table 4. Maximum Number of Beef and Dairy Farms (reporters) that Exceed Threshold Levels

	Threshold Levels (mtCO ₂ e)			
	1,000	10,000	25,000	100,000
	Maximum number of farms to exceed threshold			
BEEF FARM: AVERAGE (Emission factor: 1,016 kg CO ₂ e/head/yr)	8,186*	250 ⁺	<96	<13
BEEF FARM: HIGH (Average plus 50%: 1,524 kg CO ₂ e/head/yr)	197,410	460	150	21
DAIRY FARM (Average emission factor: 2,305kg CO ₂ e/head/yr)	3129	65	8	<8
DAIRY FARM (Average plus 50%:3,458 kg CO ₂ e/head/yr)	5,175	222	17	<8

Note: Estimates assumed the following inter-censal distribution of farms within farm size ranges with 50%, 30%, 15% and 5% in each of the quartiles. For example, there are 3,000 beef farms with 2,000 to 4,999 cattle. We assume 1,500 have 2,000 to 2,750 head, 900 have 2,750 to 3,500 head, 450 have 3,500 to 4,250 head, and 150 have 4,250 to 4,999 head.

* is the number of farms with 1,000 or more cattle, thus is a conservative estimate of maximum number of farms that could exceed the 1,000 mtCO₂e threshold).

⁺ is the number of farms with 10,000 or more head, thus is a conservative estimate for the number of farms with 9,843 or more head.

Existing Federal Data Collection Systems

There are currently no federal data collection systems that collect the information required to estimate these emissions at the entity-level. However, with the EPA 2005 Air Quality Compliance Agreement, animal feeding operations will be required to report any qualifying releases of ammonia (NH₃), hydrogen sulfide (H₂S) and volatile organic compounds (VOCs: CH₄ is a VOC, but this agreement includes non-methane VOCs) as required by section 103 of CERCLA and section 304 of EPCRA. However, since the content and mechanisms of these reporting requirements have not been set, it is difficult to gauge how the data collection systems could be used to report enteric emissions of CH₄.

References

Benchaar, C., J. Rivest, C. Pomar, and J. Chiquette, Prediction of methane production from dairy cows using existing mechanistic models and regression equations, *Journal of Animal Science*, 76, 617-627, 1998.

EPA, 2008, Inventory of US Greenhouse Gas Sources and Sinks: 1990-2006 (April 2008) USEPA #430-R-08-005.

IPCC (2007) *Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories*, Intergovernmental Panel on Climate Change.

Rice Cultivation

Rice cultivation can produce CH₄ through the biological reduction of CO₂ or organic carbon under anaerobic conditions in flooded rice fields, and N₂O through the processes of nitrification (microbial oxidation of ammonium) and denitrification (microbial reduction of nitrate) [Note: N₂O is discussed under the Agricultural soils source category]. Emission rates of CH₄ are a function of water management practice (flooding and draining), soil type (texture, organic carbon content, pH, and bulk density), climate (temperature and precipitation), rice cultivar, and other cultivation practices (e.g., fertilizers, organic amendments, tillage, herbicide use). Methane emissions from rice cultivation in the United States are highly variable, with emissions ranging from 22 to 1,490 kg CH₄/hectare/season, and double cropped rice systems yielding higher emissions (EPA 2008 Chapter 6.3).

Monitoring Emissions

There are three general approaches for monitoring CH₄ emissions from rice cultivation: direct measurement (using automated flux chambers and/or eddy correlation techniques), use of emission factors, and process modeling. Direct measurement is prohibitively expensive, over burdensome, and not suitable for producer reporting. Use of emissions factors is difficult unless there are a sufficient number of factors to capture the range in management practices and local environmental conditions. Use of process models (e.g., DNDC model) could be considered but requires systematic validation coupled with statistical modeling to quantify accuracy and precision of model estimates. Other approaches include using simple equations that would require measurement of soil conditions (e.g., soil carbon content, texture) and tracking of management activities (e.g. number of days flooded) for estimating CH₄ emissions (see Chapter 9, Willey and Chameides 2007). The *2006 IPCC Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories*, Volume 4, Equation 4.41 provides the following emission factor equations:

$$EF_{\text{rice-CH}_4} \text{ (kg/yr)} = \sum_i \sum_j \sum_k (EF_{ijk} * A_{ijk})$$

Where:

EF_{ijk} = a seasonally integrated emission factor for *i*, *j*, and *k* conditions, in kg CH₄/ha
A_{ijk} = annual harvested area for *i*, *j*, and *k* conditions, in ha/yr
i, *j*, and *k* = represent different ecosystems, water management regimes, and other conditions under which CH₄ emissions from rice may vary (e.g. addition of organic amendments).

The *i*, *j*, and *k* indices are used to adjust the EF based on a scaling factor for water management regime, organic amendments, and soil type.

Information to be Collected

The following information would need to be collected to monitor emissions using the IPCC methodology: water management practices (continuous flooding vs. intermittent drainage, number of drain events), type and amount of organic amendments, number of rice crops grown annually, and soil type.

Uncertainty

The uncertainties in the scaling factors, and hence emissions, is quite high, with uncertainty ranges more than double the default values (source *2006 IPCC Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories*, Volume 4, Table 4.22). With uncertainties greater than 100%, current emission factor approaches do not provide emission estimates suitable for mandatory reporting. Approaches for reducing uncertainties include use of statistical modeling and biogeochemical process modeling.

Reporters and Thresholds

There are approximately 485,000 hectares of rice grown on over 8,000 rice farms in the United States (USDA 2006, 2002). Table 1 presents the distribution of farms and harvested acreage of rice. Assuming the EPA average per hectare emission factors of 210 kg CH₄/hectare/season (1,785 kg CO₂e/acre) and 780 kg CH₄/hectare/season (6,632 kg CO₂e/acre) for single and double (ratoon) cropped rice (EPA 2008), respectively, Table 2 presents the size of harvested acreage required to meet the reporting thresholds of 1,000 mtCO₂e, 10,000 mtCO₂e, 25,000 mtCO₂e, and 100,000 mtCO₂e levels.

Table 1. Rice Farm Size Distribution.

Harvested Rice Farm Size (1997) – Source U.S. Census of Agriculture	Number of Farms
1 – 99 acres	1,747
100 – 249 acres	2,885
250 - 499 acres	2,812
500 - 999 acres	1,433
1,000 or more acres	414

Table 2. Acreage requirements to exceed reporting thresholds.

	Threshold Levels (mtCO ₂ e)			
	1,000	10,000	25,000	100,000
	Total number of acres to meet threshold			
Single Rice with Emission factor: 1,785 kg CO ₂ e/acre	560	5,602	14,006	56,022
Ratoon Rice with Emission Factor 6,632 kg CO ₂ e/acre	151	1,508	3,770	15,078

In 2005, total ratoon rice acreage was 53,144 acres. Florida, Louisiana and Texas were the only states that had ratoon rice with total harvested acres greater than 1,508 acres. However, only Texas had farms (64) that harvested more than 500 acres. Given the total area of ratoon rice in Texas was 21,963 acres, it is likely that only a few may harvest sufficient areas to trigger the 10,000 mtCO₂e and 25,000 mtCO₂e thresholds. Given the high acreage requirements for single rice, it is also unlikely that there are many farms that reach the threshold levels.

Existing Federal Collection Systems

There are no current systems that collect information on water management, organic amendments, rice cultivars, and soil property information.

References

EPA, 2008, Inventory of US Greenhouse Gas Sources and Sinks: 1990-2006 (April 2008) USEPA #430-R-08-005.

USDA, 2002, NASS Agricultural Census, <http://www.agcensus.usda.gov/Publications/2002/index.asp>

USDA, 2006 USDA Crop Production Summary,
<http://usda.mannlib.cornell.edu/MannUsda/viewDocumentInfo.do?documentID=1046>

Willey, Z. and Chameides, B, 2007, *Harnessing Farms and Forests in the Low-Carbon Economy: How to Create, Measure and Verify Greenhouse Gas Offsets*, Duke University Press, Durham and London.

Field Burning of Agricultural Residues

Agricultural field crop residues include stalks and stubble or stems, leaves, and seed pods. Farmers often choose to remove crop residue from their fields by directly burning the material. However, open field burning of residue results in a complex mix of aerosols and GHG emissions to the atmosphere that include PM, CH₄, CO, NO_x, and N₂O (Guoliang et al. 2007; Gupta et al. 2004; and others).

Monitoring Emissions

Techniques for calculating emissions from residue burning on field crops (including rice, wheat, sugarcane, barley, corn, soybeans, and peanuts) are discussed in EPA 2007, and are based on the *Revised 1996 IPCC Guidelines*. Emissions are calculated using a series of step calculations and crop-specific statistics. There is no direct measurement technique suitable for capturing emissions from this disperse source category. There are, however, hybrid-type approaches that combine satellite-derived data with ground-report databases, such as SMARTFIRE (<http://www.getbluesky.org/smartfire>).

Information to be Collected

Specific data needed for determining emissions by crop include annual crop production (lbs), residue/crop ratio, proportion of crop produced in fields where residue is to be burned (%), dry matter content of the residue (%), crop burn efficiency (%), crop combustion efficiency (%), and the carbon/nitrogen content of the residue to be burned (lbs of C and N/ lbs of dry matter).

Uncertainty

Emission estimation techniques are subject to a large amount of uncertainty (EPA 1999) and would require extensive effort on the part of farmers to consistently record the needed crop statistics. Emission ratios also vary significantly between the flaming and smoldering phases of a fire. CO₂ and N₂O are mainly emitted during the flaming stage, while CH₄ is mainly emitted during the smoldering stage. The relative importance of these two stages will vary between fires in different ecosystems and under different climatic conditions. Since simple emission factors are not available without direct monitoring of emission during burning, growers will be unable to estimate emissions from burning of agricultural residue.

Reporters and Thresholds

Reporters would be the entity that controls how crops are grown or grassland is managed on the land (e.g. lessee for leased lands). In 2007, there were 2.08 million farms in the United States with a total land in farms of 930.9 million acres with an average farm size of 449 acres (USDA Agricultural Statistics Board 2008). In 2002, there were 14,644 farms that harvested over 5,000 acres (USDA 2002 Agricultural census, Volume 1, Table 9). Figure 1 provides the size class distribution of farm.

For demonstration purposes, we calculated the acreage requirements for burning of corn residues to meet the reporting thresholds under consideration. We assumed an average of 75 lbs of corn residue per bushel production of corn (source from biomass energy study in Wyoming, http://www.wyomingbusiness.org/pdf/energy/Biomass_CropResidue.pdf). With averaged corn yields of 140 bushels per acre, we estimate average corn residue of 10,500 lbs/acre. Based on greenhouse gas emission ratios and crop residue characteristics from Tables 6-23 and 6-24 in EPA 2008, burning corn

residue produces a total of 324 kg CO₂e/acre (78 kg CO₂e/acre from nitrous oxide and 246 kg CO₂e/acre from methane). EPA (2008) estimates that approximately 3% of crop residues are burned each year (excluding rice where a much higher percentage of residue is burned annually).

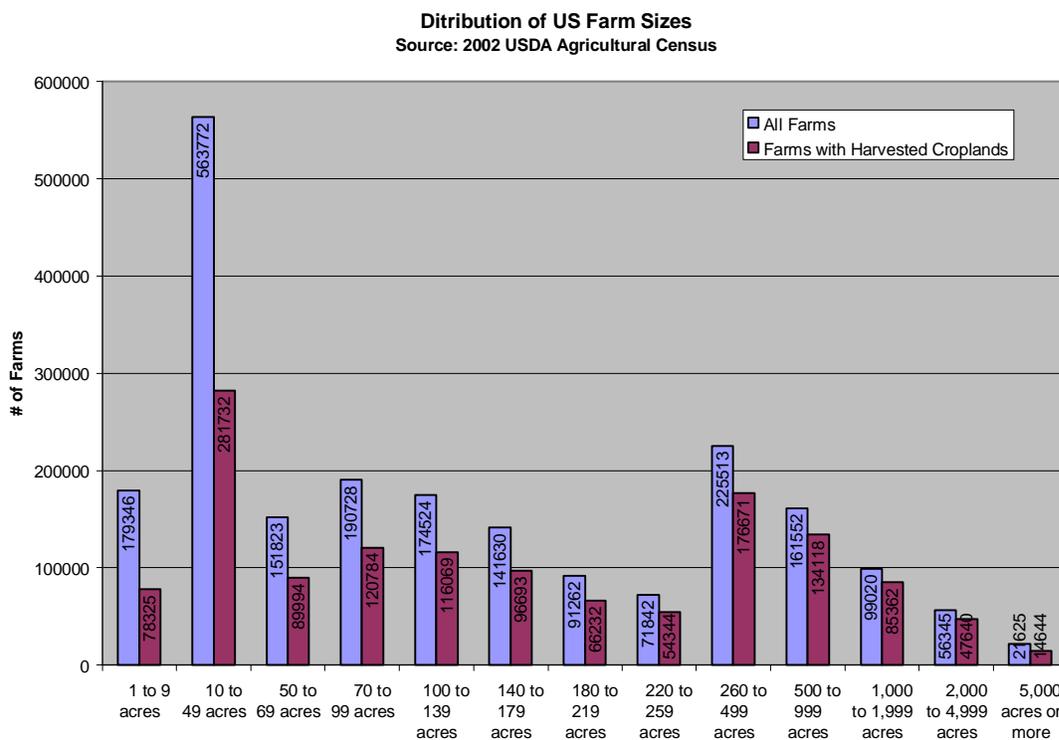


Figure 1. Size class distribution of United States farms based on acreage of cultivated lands
[Note: Data are presented for all farms and those farms that have harvested cropland.]

Table 1. Acreage requirements (corn example) to exceed reporting thresholds.

	Threshold Levels (mtCO ₂ e)			
	1,000	10,000	25,000	100,000
	Total number of acres to meet threshold			
Corn Residue Example: 324 kg CO ₂ e/acre	3,086	30,864	77,160	308,642

Existing Federal Data Collection Systems

There are no existing federal collection systems that collect the information needed to estimate greenhouse gas emissions from agricultural residue burning at the entity-level.

References

Andrews, SS, 2006. Crop residue removal for biomass energy production: Effects on soils and recommendations. United States Department of Agriculture (USDA), Natural Resource Conservation Service, White paper, 25 pp.

- EPA, 2008, Inventory of US Greenhouse Gas Sources and Sinks: 1990-2006 (April 2008) USEPA #430-R-08-005.
- Guoliang et al., 2008. Investigation on emission factors of particulate matter and gaseous pollutants from crop residue burning. *Journal of Environmental Sciences* (20) 50-55.
- Gupta et al., 2004. Residue burning in rice–wheat cropping system: Causes and implications. *Current Science* (87) 1713-1717.
- Pathak, H and R Wassmann, 2007. Introducing greenhouse gas mitigation as a development objective in rice-based agriculture: I. Generation of technical coefficients. *Agricultural Systems* (94) 807–825
- U.S. Environmental Protection Agency (EPA), Office of Research and Development. Emissions of organic air toxics from open burning, EPA-600/R-02-076, 62 pp.
- U.S. Environmental Protection Agency (EPA), Emission Inventory Improvement Program (EIIP) Volume VIII, 1999. Methods for estimating greenhouse gas emission from burning of agricultural crop wastes. Chapter 11 – Agricultural crop wastes, 25 pp.
- Wang, WJ and RC Dalal, 2006. Carbon inventory for a cereal cropping system under contrasting tillage, nitrogen fertilisation and stubble management practices. *Soil & Tillage Research* (91) 68–74.

Composting

Both N₂O and CH₄ can be emitted during the composting process. While CH₄ is produced only under anaerobic conditions, the compost pile itself tends to be heterogeneous, such that N₂O is produced in aerobic sections of the compost and CH₄ is produced in anaerobic sections of compost that are created due to excessive moisture or inadequate mixing. It is estimated that the CH₄ emissions total <1% to a few percent of the C present in the waste material, while N₂O emissions total 0.5% to 5% of the initial N present in the waste material (EPA 2008). Nitrous oxide emissions from compost generally decrease over time, unless the organic material is composed at least partially of manure (He et al. 2000, Morand et al. 2005). The mass of material composted has jumped nearly 400% between 1990 and 2006, due to steady growth in population as well as state and local regulations discouraging landfilling of yard trimmings, and includes primarily yard trimmings (grass, leaves, and tree and brush trimmings) and food scraps from residences and commercial establishments (such as grocery stores, restaurants, and school and factory cafeterias) (EPA 2008).

Monitoring Emissions

Methods for measuring N₂O and CH₄ emissions from compost usually involve closed compost systems (Morand et al. 2005) or equipment such as dynamic chambers (Osada and Fukumoto 2001). Development of decay curves for typical compost materials and compost operation sizes will be useful for ongoing measurement and monitoring of emissions from compost.

To apply the IPCC default methodology for estimating N₂O and CH₄ emissions from composting operations, the mass of wet waste composted (M) is multiplied by an emission factor (EF_i) (typically 4 g CH₄ per kg of wet organic waste and 0.3 g N₂O per kg of wet organic waste). The relevant equation is:

$$E_i = M \times EF_i \quad (\text{EPA 2008})$$

Information to be Collected

The following information would need to be collected to monitor emissions using the IPCC methodology: mass of material composted, and associated emission factors.

Uncertainty

In 2006, compost was included in the U.S. GHG Inventory for the first time. That report estimated annual emissions of N₂O and CH₄ from composting operations, not including backyard composting operations, at 3.3 MMTCO₂e, with a quantitative estimate of uncertainty (with 95% confidence) between 1.7 and 5.0 MMTCO₂e annually (EPA 2008). While uncertainty is held constant at +/-50% in the IPCC Tier 1 methodology, additional uncertainty in N₂O and CH₄ emissions from composting can be attributed to the scale of the operation (Fukumoto et al. 2003), the turning schedule of the compost, and the composition of the inputs.

Reporters and Thresholds

The U.S. Economic Census estimates that there are 17 establishments that produce compost as fertilizer in the United States, with annual shipments of roughly \$57.0 million. Clearly most composting operations are small-scale endeavors, conducted on farms or in backyards nationwide.

Using the equation above and assuming a global warming potential (GWP) of 21 for CH₄, in order to meet the 1,000 mtCO₂e/ year emission threshold for 10,000 mtCO₂e/ year emission threshold for CH₄ alone, a composting operation would need to compost 11,905 tons of waste annually (Table 1). To meet the 10,000 mtCO₂e/ year, 25,000 mtCO₂e/ year and 100,000 mtCO₂e/ year thresholds for CH₄ emissions, an entity would need to compost 119,048 tons, 297,619 tons, and 1.2 million tons of wet waste annually, respectively (Table 1). Assuming a GWP of 310 for N₂O, the mass of waste composted would be somewhat lower in order to meet the reporting threshold based on N₂O emissions alone. Specifically, a facility would need to compost 10,753 tons, 107,527 tons, 268,817 tons, and 1.08 million tons of wet waste annually to meet the threshold reporting targets based on N₂O (Table 1). Practically, a compost operation would emit both gases simultaneously, thus reducing the volume of waste composted to meet the same emission threshold. Assuming the same emission factors, the waste needed to meet the threshold for reporting would be 5,650 tons for the 1,000 mtCO₂e threshold, 56,497 tons for the 10,000 mtCO₂e threshold, 141,243 tons for the 25,000 mtCO₂e threshold and 564,972 tons for the 100,000 mtCO₂e threshold (Table 1).

Table 1. Mass of wet organic waste (in tons) needed to meet threshold reporting targets for annual CH₄ and N₂O emissions, separately and in combination, from composting operations.

	1,000 mtCO ₂ e	10,000 mtCO ₂ e	25,000 mtCO ₂ e	100,000 mtCO ₂ e
N ₂ O	10,753	107,527	268,817	1,075,269
CH ₄	11,905	119,048	297,619	1,190,476
combined	5,650	56,497	141,243	564,972

	1,000 mtCO ₂ e	10,000 mtCO ₂ e	25,000 mtCO ₂ e	100,000 mtCO ₂ e
N ₂ O	10,753	107,527	268,817	1,075,269
CH ₄	11,905	119,048	297,619	1,190,476
combined	5,650	56,497	141,243	564,972

Existing Federal Data Collection Systems

There are no current systems that collect the data needed for entity reporting, though existing systems for managing waste could be adapted to track the amount of organic waste directed to compost operations.

References

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Agricultural Soil Carbon Sequestration

The top one meter of soil is estimated to have 1,502 billion metric tons of soil organic carbon (Schlesinger, 1997, Jobbagy and Jackson 2000), which is approximately 3 times the size of other terrestrial carbon pools (i.e. biomass and dead organic matter). The top one meter of agricultural soils contains approximately 170 billion metric tons of C (Cole et al., 1996). Soil organic carbon (SOC) pools in agricultural soils are highly dynamic as agricultural processes, such as tillage, change the temperature and moisture regimes in soils and rate, quantity and quality of organic inputs. Thus, rates of SOC sequestration and oxidation (release) vary based on SOC pools, soil type, climate, and agricultural management.

Monitoring

In general, there are three approaches for monitoring changes in SOC from cultivation of agricultural soils: direct measurement, use of activity-based emission factors, and process modeling. Accuracy of direct measurement of SOC pools in agricultural soils vary with the scale of the measurements from ± 0.1 MT/hectare at plot scale and ± 1 MT/hectare at farm scale (Kimble et al. 2002). However, the cost of direct measurements can be expensive and overly burdensome for mandatory reporting due to the sampling design requirements to meet desired accuracy (e.g., sample depth, # of soil samples, frequency of sampling) and costs of analyzing soil samples (Willey and Chameides 2007). Performance or activity-based approaches (e.g. CCX, IPCC) use regionally-based emission factor approaches for monitoring SOC changes of time. While these approaches may not capture the influence of different soils or climate conditions within the region, they are thought to capture average regional changes in SOC, as opposed to farm-specific SOC changes. Process models (e.g., CENTURY, EPIC, DNDC) simulate the biogeochemical processes that drive crop growth and SOC dynamics. An advantage of process models is that they can be used for full GHG accounting to look at the relationship between SOC sequestration and subsequent emissions of N_2O (see Li et al. 2005 and Six et al. 2004). Process models have been used to generate data for web-based modeling tools (e.g., COMET-VR and C-LOCK) to enable growers to estimate changes in SOC based on local soils and climate and their specific management practices.

The IPCC methodology accounts for net C emissions (sinks and sources) for three categories of agricultural soils: (i) changes in C stocks of mineral soils due to cropland management practices; (ii) changes in C stocks from organic soils that are drained; and (iii) liming of agricultural soils. For mineral soils, changes in soil carbon stocks are estimated based on reference carbon stocks and stock change factors related to land use (long-term cultivated, paddy rice and set aside), tillage practices (full till, reduced till or no-till) and organic matter inputs (low, medium, high without manure, and high with manure). For drained organic soils, the IPCC Tier 1 method for estimating changes in soil carbon content:

$$\Delta C_{\text{organic}} \text{ (t C/yr)} = \sum_c (A * EF)_c$$

Where:

EF = emission factor for climate region c , in tC/ha/yr
A = land area of drained organic soils in climate region c , in ha

Information to be Collected

The following information is required to apply the IPCC methods for estimating change in soil organic carbon stocks: crop type (characterized by amount of crop residue), local climate, soil type, tillage practices and use of organic amendments.

Uncertainty

A range of techniques are used to estimate uncertainty in process model estimates, including standard error propagation and simple empirical models, to more computationally-intensive Monte Carlo numerical approaches (Ogle et al. 2007). The IPCC approach for estimating changes in SOC stocks uses a set of stock change factors that are adjusted based on climate, soil type, tillage practices, and organic carbon inputs. IPCC estimates that errors in using their stock change factor approach for SOC sequestration over a 20-year period ranges from $\pm 4\%$ (for low C input systems) to $\pm 90\%$ (for high C input systems, like rice residue incorporation). Since process models offer the best opportunity for reducing uncertainty in SOC sequestration, rigorous uncertainty analyses, such as the current efforts to improve the uncertainty estimator in COMET-VR, are needed.

In summary, the required data collection for accurate reporting and subsequent measurement of changes in organic carbon stocks in agricultural soils is subject to large uncertainties and burdensome calculations, whether it is for reporting loss or sequestration of soil carbon.

Reporters and Thresholds

In 2007, there were 2.08 million farms in the United States with a total land in farms of 930.9 million acres with an average farm size of 449 acres (USDA Agricultural Statistics Board 2008). In 2002, there were 14,644 farms that harvested over 5,000 acres (USDA Agricultural census, Volume 1, Table 9). Rates of carbon loss or gain in agricultural soils are highly variable and can be difficult to estimate. Using IPCC stock change factors for cool temperate dry region emissions of carbon, and agricultural lands with low biomass inputs and full conventional tillage, average emission rates can be as high as 0.93 mtCO₂e/acre/yr. Table 1 presents the acreage required to meet the reporting thresholds at this emission rate.

Table 1. Example acreage requirement for reporting thresholds

	Threshold Levels (mtCO₂e)			
	1,000	10,000	25,000	100,000
	Total number of acres to meet threshold			
Mineral Soils – Cold Temperate Region, low inputs, full tillage	1,075	10,753	26,881	107,527

Note: Since the uncertainties (see discussion below) are high, this is meant to be an illustrative example.

To put SOC sequestration in agricultural soils in perspective with possible reporting thresholds for emissions, assuming the upper range of SOC sequestration in the Kimble et al. (2002) summary estimates, a farmer would need to switch 12,200 acres from plow-till to no-till or shift 5,900 acres to Conservation Reserve Program (CRP) to sequester 10,000 mtCO₂e/yr.

Drainage of organics soils can lead to high rates of soil carbon loss. On average from 1993 to 2006 drainage of organic soils in the United States released 27.7 MMTCO₂e/yr (EPA 2008). Approximately 640,000 hectare of organic soils were drained during this time period. Thus the average carbon flux was 43,281 kg CO₂e/ha. Table 2 present a summary analysis of acreage required to meet candidate reporting thresholds for drainage of organic soils.

Table 2. Acreage requirements for drainage of organic soils to exceed reporting thresholds.

	Threshold Levels (mtCO ₂ e)			
	1,000	10,000	25,000	100,000
	Total number of acres to meet threshold			
Organic Soils – Avg emission rate 43,281 kg CO ₂ e/ha	57	571	1,427	5,707

Figure 1 present the size distribution of U.S. farms. Approximately 7% of all farms have over 1,000 acres. The total area of cropland on organics soils is 720,000 ha which represents less than 0.5% of the total cropland area. Assuming an even distribution of farm size on mineral and organic soils, we expect approximately 0.035% of all farms are cultivating more than 1,000 acres of organic soils. Thus, while the emission rates can be high for drained organic soils, the likely number of reporters would be small.

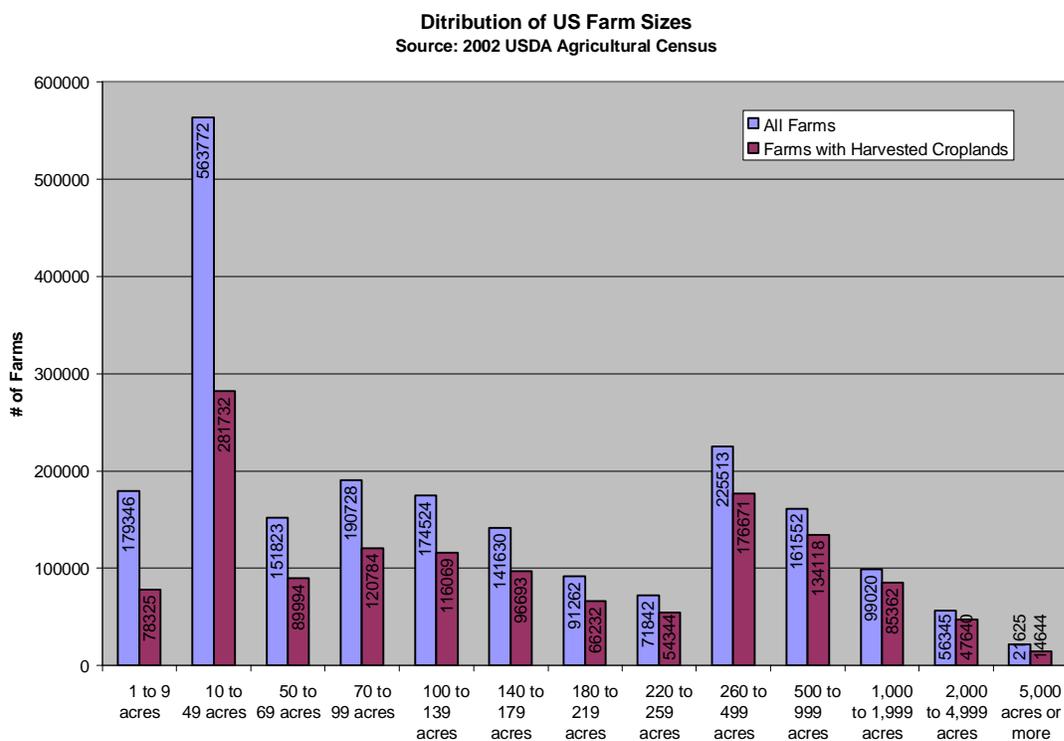


Figure 2. Size class distribution of US farms based on acreage of cultivated lands. Data are presented for all farms and those farms that have harvested cropland.

Existing Federal Data Collection Systems

There are no current systems that collect all the necessary data and information for accurate reporting of changes in organic carbon stocks in agricultural soils.

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Agricultural Soil N₂O Emissions (including fertilizer use)

Nitrous oxide is produced naturally in soils through the microbial processes of nitrification and denitrification both through anthropogenic and natural causes.

The IPCC considers all emissions of N₂O from managed lands to be anthropogenic. The U.S. GHG Inventory conforms to IPCC guidance, and accounts for all emissions from managed lands, which includes natural background N₂O emissions. In 2006, N₂O emissions from agricultural soil management were 265.0 MMTCO₂e, which is 72% of all U.S. N₂O emissions, and 3.8% of all U.S. GHG emissions.

Anthropogenic emissions of N₂O from agricultural soils consist of both direct and indirect emissions that result from inputs of N, and management practices that lead to a greater release of mineral N to the soil on managed lands. Direct emissions result from a variety of management practices, including: fertilization; application of managed livestock manure and other organic materials such as sewage sludge; deposition of manure by grazing animals; production of N-fixing crops and forages; retention of crop residues; and drainage and cultivation of organic cropland soils (i.e., soils with a high organic matter content, otherwise known as histosols). Other agricultural soil management activities, including irrigation, drainage, tillage practices, and fallowing of land, can influence N mineralization in soils and thereby affect direct emissions. Indirect emissions of N₂O occur through two pathways: (1) volatilization and subsequent atmospheric deposition of applied N, and (2) surface runoff and leaching of applied N into groundwater and surface water. (See attached figure of N flows resulting in emissions of N₂O.)

Monitoring

In general, there are three approaches for monitoring N₂O emissions from management of agricultural soils: (1) direct measurement (using automated flux chambers and/or eddy correlation techniques), (2) use of emission factors, and (3) process modeling. Direct measurement is prohibitively expensive due to the cost of equipment and need for continuous measurements to capture episodic emission events. Use of a single emissions factor, like the IPCC factor of 1%, based on amount of applied nitrogen can result in large uncertainty at the farm level as field data have shown that actual emission rates can range from 0.1% to almost 10% of applied fertilizer. Use of process models (e.g., DAYCENT, DNDC model) is promising but can be data intensive and requires systematic validation coupled with statistical modeling to quantify accuracy and precision of model estimates. A hybrid option that combines the IPCC emission factor and modeling approaches is the use of a model such as the one under development for NRCS using preset DAYCENT runs. This model could be used in combination with the COMET-VR soil carbon model to estimate soil N₂O emissions, utilizing activity data similar to that required by the IPCC methodology, but would be an improvement in accuracy over the standard IPCC approach while keeping the data requirements at a reasonable level.

Information to be Collected

Application of N at a farm results in direct emissions onsite and also offsite through volatilization, leaching/runoff of N and later deposition where the N is made available for nitrification/denitrification, (i.e., indirect emissions). Accounting for these indirect emissions is extremely uncertain, as it is rarely known where the N is eventually emitted as N₂O. For emissions estimates, it is only practical to include direct emissions resulting from inputs of N by the landowner. Indirect emissions (those resulting from N that was not directly applied to the land) are not under the control of the landowner and very difficult to

quantify. Reporting N₂O emissions onsite and not reporting N₂O offsite would, however, result in incomplete estimates.

In order to capture all of the direct N₂O emissions resulting from application of N to soils, it would be necessary for farmers to report on a number of different N inputs. Synthetic N and organic N inputs (e.g., synthetic fertilizer, manure, sewage sludge) are the only inputs that be measured with reasonable accuracy and minimal burden by a landowner. N resulting from mineralization of organic matter (plant residue or soil organic matter) would be very uncertain. This leaves synthetic and organic inputs of N as the only potentially reportable inputs.

Table 4. Activity data for calculation N₂O emissions

Activity data for N inputs	Feasibility of data collection	Share of N ₂ O Emissions from Agricultural Soils
Synthetic N application (at farm level)	High	26%
Urine and Dung (from grazing animals) N input to land	Medium/Low	9%
Organic Amendments (including sewage sludge, manure, compost)	Medium/Low	5%
Crop residue N contribution	Low	10%
Other (Mineralization of soil organic matter, asymbiotic fixation of N from atmosphere)	Very Low	50%

Uncertainty

While some input data can be collected with reasonable certainty, the estimation of N₂O emission from these inputs varies greatly spatially and temporally. Until the available modeling-based approaches can be implemented in a routine manner, efforts for reporting N₂O emissions from agricultural soils will be hampered with emission factor approaches that suffer from large uncertainties.

Reporters and Thresholds

All land-use types occurring in the United States (cropland, grassland, forestland, settlements and wetlands) emit N₂O. Thus all landowners could potentially be reporting entities. In 2007, there were 2.08 million farms in the United States with a total land area of 930.9 million acres, and an average farm size of 449 acres (USDA Agricultural Statistics Board 2008).

Analysis for the GHG reporting rulemaking is focusing on thresholds of 1,000 mtCO₂e, 10,000 mtCO₂e, 25,000 mtCO₂e, and 100,000 mtCO₂e. Using average fertilizer application rates and IPCC emission factor N₂O estimation methodologies, it becomes apparent that even at the highest N fertilization rate of 180 lbs N/acre, it would take a farm of over 25,000 acres to equal the 10,000 mtCO₂e threshold. Given that the USDA Farm Census from 2002 reports as its largest farm size 5000+ acres (see Figure 1), there is a very low probability that any farm in the United States would meet even the 10,000 mtCO₂e threshold. (See Table 1 below.)

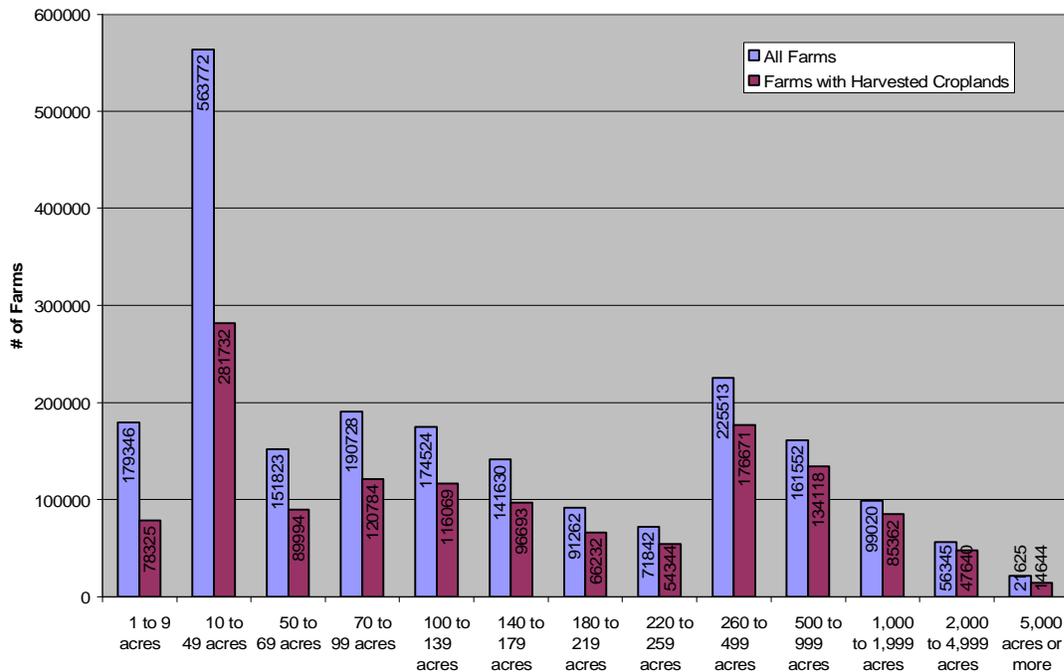


Figure 1. Distribution of US Farm Sizes.

Source: 2002 USDA Agricultural Census

Table 1. Threshold analysis with IPCC Factors

N Fertilizer Rates In US	Number of acres to reach 10,000 mtCO ₂ e threshold
Wheat: 68 lbs/acre	68,488
Cotton: 92 lbs/acre	49,019
Corn (Avg. rate) 137 lbs/acre	33,112
Corn (High value) 180 lbs/acre	25,062

Another way of performing this analysis is to use data from the U.S. GHG Inventory (EPA 2008) and estimate area-based emission factors for direct N₂O emissions from all N inputs to cropland as well as isolating just synthetic N inputs (See Table 2 below).

Table 2. Threshold analysis with US GHG Inventory Factors

Category	N ₂ O Emission Rate (kg CO ₂ e/acre)	Number of Acres to reach 10,000 mtCO ₂ e Threshold
Cropland: Synthetic N Additions	134	74,626
Cropland: All N Inputs	347	28,818
Grassland: All N Inputs	104	96,000

It becomes apparent after performing these analyses and reviewing farm size data that it is very unlikely that any farm in the United States would meet a 10,000 mtCO₂e threshold.

Existing Federal Data Collection Systems

There are no current systems that collect the data needed for entity reporting.

Settlement N₂O Emissions (including fertilizer use)

Source Category

N₂O is emitted from soils in settlements due to nitrification and denitrification. While typical nitrification and denitrification rates in natural systems vary primarily with moisture and temperature, in settlements lawn fertilization and irrigation can increase rates of N₂O release by as much as 15 times during the days immediately following fertilization (Bremer 2006, Hall et al. 2008). Significant release of CH₄ has not been measured from urban soil, and – overall – soils in urban settlements are probably a net sink for CH₄ (Kaye et al. 2004).

Monitoring Emissions

Application rates of fertilizer are quite heterogeneous and can vary by homeowner, but do correlate with socioeconomic characteristics, neighborhood, and lawn size (Law et al. 2004, Zhou et al. 2007). Despite these correlations, empirically predictive methods for understanding fertilizer application rates do not yet exist. Monitoring of N₂O emissions from settlements are also complicated by the rapid change in settlement land area, as the overall land area devoted to settlements increased by 32.2% between 1990 and 2006, resulting in an increase in N₂O flux by 48% over the same period (EPA 2008). Current methodology for estimating N₂O flux from settlements remaining settlements is based on aggregate fertilizer applications rather than on per-unit-area estimates, thus there are no region- or area-specific emission factors appropriate for settlements. Since lawn areas tend to be fairly homogeneous, however, one can estimate the per-unit-area emissions by dividing the total N₂O flux from fertilizer application (1.5 MMTCO_{2e}) by the total area of turfgrass in the United States (32 million acres [Milesi et al. 2005]) for an overall nationwide average of 0.05 mtCO_{2e} per acre of turfgrass per year.

Information to be Collected

The following information would need to be collected to monitor emissions: area subject to fertilizer application, type of fertilizer and application rate. Also needed are accurate estimates of emission factors for settlements remaining settlements.

Uncertainty

N₂O flux from settlements depends on a large number of variables in addition to N inputs, including organic C availability, O₂ partial pressure, soil moisture content, pH, temperature, and irrigation/watering practices. The effect of the combined interaction of these variables on N₂O flux is complex and highly uncertain. The IPCC default methodology only accounts for variations in fertilizer N and sewage sludge application rates, such that all settlement soils are treated equivalently. A quantitative uncertainty analysis of N₂O flux from settlements remaining settlements found that the 95% confidence interval ranged from -59% to +163% of the estimated 2006 emission estimate of 1.5 MMTCO_{2e} (EPA 2008).

Identification of Reporters

Estimates of the turfgrass area covered by home lawns in the United States range from 17.7 million (EPA 2007) to 21 million acres (Bormann et al. 2001). A 2005 remote sensing study estimated the total land area covered by turfgrass in the United States (including home lawns as well as recreational fields, commercial and industrial parks, golf courses, etc.) to be roughly 32 million acres, corresponding to 1.9% of total U.S. land area (Milesi et al. 2005). The 2000 U.S. Census reports 105.5 million households in the United States, roughly 80% of which maintain a private lawn (Tempelton et al. 1998). While the average

lawn size in the United States varies with region, the national mean lawn size is 0.3 acres (Vinlove and Torla 1995).

At the nationwide average N₂O emission rate of 0.05 mtCO₂e per acre per year, an entity would need to reach 20,000 acres of fertilized turfgrass in order to be eligible for reporting under the 1,000 mtCO₂e/ year threshold and 200,000 acres of fertilized turfgrass in order to be eligible for reporting under the 10,000 mtCO₂e/ year threshold. Entities larger than 533,000 acres would be eligible under the 25,000 mtCO₂e/ year threshold, and entities larger than 2.1 million acres would be required to report under the 100,000 mtCO₂e/ year threshold. For reference, an 18-hole golf course can be built on as little as 100 acres, and few courses are larger than 1000 acres.

Existing Federal Data Collection Systems

There are no current systems that collect the data needed for entity reporting.

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Forest Land N₂O and CH₄ (including fertilizer use and forest fires)

Nitrous oxide and CH₄ are emitted in this source category primarily via emissions from soils and wildfire. N₂O is emitted from forest soils via nitrification and denitrification (Carnol and Ineson 1999, Davidson et al. 1993, Kester et al. 1997, Wolf and Brumme 2002). Dry upland forest soils are sinks for CH₄ (Castaldi et al. 2006, DelGrosso et al. 2000, Hein et al. 1997, Jang et al. 2006, Wuebbles and Hayhoe 2002), though some studies have suggested that CH₄ may be emitted from wet forest soil under natural conditions due to anaerobic decomposition (Megonigal and Guenther 2008, Ullah et al. 2008). Wildfire emissions of N₂O and CH₄ from forests depend on the amount of biomass burned, together with the expected emission factors for the biomass involved in the fire.

In the United States, forest fires caused the release of 24.6 MMTCO₂e as CH₄ and 2.5 MMTCO₂e as N₂O in 2006 (EPA 2008). These fire-related emissions totaled 27.1 MMTCO₂e, or 73% of the non-CO₂ emissions from the LULUCF sector in that year. This 2006 emissions total was a five-fold increase from the 5.0 MMTCO₂e (0.5 MMTCO₂e as N₂O, 4.5 MMTCO₂e as CH₄) attributable to fire in 1990, when the forest-fire-related non-CO₂ emissions totaled only 38% of the non-CO₂ emissions from the LULUCF sector. While recent research has yielded important information about dry upland soils as sinks for CH₄, this phenomenon has not yet been quantified at the national scale. Globally, a sink of roughly 30 MMTCH₄ per year (630 MMTCO₂e per year) in upland soils has been estimated. In the United States, this sink would partially offset the emissions from wildfire, as the ratio of upland soils to wetland soils is large.

Monitoring Emissions

Direct measurement of trace gas fluxes such as N₂O and CH₄ typically involve chamber-based instrumentation that is quite costly and time-consuming to install and maintain. The measurements collected tend to be quite variable over space and time, and can depend substantially on microclimatic variables such as temperature and moisture. Thus collection of direct measurements of CH₄ and N₂O fluxes, and even interpolation of existing trace gas measurements, is difficult for large scales. While fertilizer application could be used as a proxy for N₂O emissions from soils, substantial uncertainty exists related to fertilization rates, area of land receiving fertilizer, and emission factors. Non-CO₂ gases emitted from forest fires depend on several variables, including forest area and C density, emission ratios, and combustion factor values (proportion of biomass consumed by fire). In the IPCC default methodology (IPCC 2006), CH₄ and N₂O emissions from fire are calculated by multiplying the total estimated C emitted from forest burned by gas-specific emissions ratios and conversion factors. The relevant equation is:

$$L_{fire} = A \cdot MB \cdot Cf \cdot Gef \cdot 10^3$$

Where

L = total emissions from fire (in tonnes of GHG emitted)

A = spatial extent of fire (area burnt, ha)

M = mass available for combustion (tonnes per ha)

Cf = combustion factor (the proportion of biomass that is consumed by fire) (dimensionless)

Gef = emission factor (tonnes GHG emitted per kg biomass combusted)

At large scales, the extent of wildfires can be measured using satellite based monitoring programs such as those spearheaded by the Fire and Environmental Research Applications Team

(<http://www.fs.fed.us/pnw/fera/fccs/index.shtml>) and the MODIS Active Fire Mapping Program at the USDA Forest Service (<http://activefiremaps.fs.fed.us/>). These can be paired with information about forest inventory developed from the USDA Forest Service Forest Inventory and Analysis Program, but there is likely a minimum area below which this approach would not be feasible. This minimum area is determined by the spatial accuracy of the spatial input layers -- specifically, the pixel size of the satellite imagery being used as well as the relative accuracy of the classification. Small ownerships would not be well represented by a satellite monitoring approach. A modeling approach can also be used, at small scales or together with maps of the spatial extent of fires. Process models such as Consume 2.1 (and 3.0) can be used to predict trace gas emission from wildfire, but these models must still be parameterized with field data about the biomass involved in the fire and the fire severity (http://www.fs.fed.us/pnw/fera/research/smoke/consume/consume_download.shtml). In addition, there are also hybrid-type approaches that combine satellite-derived data with ground-report databases, such as SMARTFIRE (<http://www.getbluesky.org/smartfire>).

Information to be Collected

The following information would need to be collected to monitor emissions using the IPCC methodology. For non-fire N₂O losses, fertilizer application rate, and type of fertilizer used would be needed. For fire-related N₂O and CH₄ losses, the required information includes spatial extent of fire, severity of fire (i.e. proportion of biomass consumed by fire), and C density of burned forest.

Uncertainties

For N₂O emissions from forest soils, uncertainties relate to variability in human-induced parameters such as fertilizer inputs and tree planting/ harvesting cycles, as well as biogeochemical processes including organic C availability, O₂ partial pressure, soil moisture content, pH, and temperature (EPA 2008). Quantitative analysis suggests uncertainties in inventory-based estimates of N₂O flux between +211% and -59% (EPA 2008). Uncertainty also exists “due to lack of sufficient field data, sampling conditions with a tendency to over-represent one mode of combustion over the other, and differences in the types of measurements (tower vs. ground-based vs. aircraft measurements). Furthermore, emission factors vary as the fire season progresses due to changing moisture conditions (Hayhoe, pers. comm.). These uncertainties result in quantitative uncertainty estimates of between +71% (CH₄)/ +75% (N₂O) and -69% (CH₄ and N₂O) around existing estimates of wildfire emissions (EPA 2008).

Reporters and Thresholds

There are 620 million acres of forest land in the United States, of which 393 million acres (roughly two-thirds) are in private ownership, including a combination of family forestland owners and land held by partnerships and corporations (Butler and Leatherberry 2004). An estimated 10.3 million family forest owners in the United States collectively control 42% of forested land in the United States (family forest land is owned by individuals not incorporated as a legal entity). Most of these (88%) family forestland owners are in the Eastern United States; the remaining 12% own land dispersed across the Western states. Owners with 50+ acres hold 69% of family forestland across the United States, but account for 11% of family forest owners. Public forestland is predominantly owned by the Federal Government in the West, and by State and county governments in the East. Public land accounts for 69% of the forest land in the West, and 17% of the forest land in the East (USDA 2001).

The IPCC methodology for quantifying non-CO₂ GHG emissions from wildfires and prescribed fires describes a range of emission factors from 0.06 g N₂O per kg biomass burned (for biofuel burning) to 0.26 g N₂O per kg of biomass burned (for extratropical forests). For CH₄, the low emission factor estimate is 2.3 g CH₄ per kg biomass burned (for savanna and grassland), and the high emission factor is 6.8 g CH₄ per kg biomass burned (for tropical forest). Clearly there is biome-specific variation in these

factors, but emission factors with finer spatial or biome-specific resolution are not available. Similarly, a range of pre-burn biomass (M) and proportion burned (Cf) are available. Assuming the IPCC default of 0.45 for Cf in “temperate forests,” we can identify a threshold reporter size for wildfire extent to be eligible for entity-level reporting.

N₂O: Assuming the highest emission factor (0.26 g N₂O per kg burned) and a high forest C density of 300 tons C per ha, a wildfire of 227 acres would be eligible for entity reporting if the threshold were 1,000 mtCO₂e and a wildfire of 2,270 acres would be eligible if the threshold were 10,000 mtCO₂e. A wildfire of 5,675 acres would be required if the threshold for reporting were 25,000 mtCO₂e, and a wildfire of 22,700 acres would meet the 100,000 mtCO₂e threshold (Table 1). Assuming the lowest emission factor (0.06 g N₂O per kg of biomass burned) and an average forest density of 150 tons C per ha, a wildfire of 1,967 acres would be eligible for entity reporting at an emissions threshold of 1,000 mtCO₂e and a wildfire of 19,673 acres would be eligible at an emissions threshold of 10,000 mtCO₂e. A wildfire of 49,184 acres would be required at an emissions threshold of 25,000 mtCO₂e, and a wildfire of 196,734 acres would be eligible for reporting under an emissions threshold of 100,000 mtCO₂e (Table 1).

CH₄: Assuming the highest emission factor (6.8 g CH₄ per kg burned) and a high forest C density of 300 tons C per ha, a wildfire of 128 acres would be eligible for entity reporting if the threshold were 1,000 mtCO₂e and a wildfire of 1,281 acres would be eligible if the threshold were 10,000 mtCO₂e. A wildfire of 3,203 acres would be required if the threshold for reporting were 25,000 mtCO₂e, and a wildfire of 12,813 acres would meet the 100,000 mtCO₂e threshold (Table 2). Assuming the lowest emission factor (2.3 g CH₄ per kg of biomass burned) and an average forest density of 150 tons C per ha, a wildfire of 758 acres would be eligible for entity reporting at an emissions threshold of 1,000 mtCO₂e and a wildfire of 7,576 acres would be eligible at an emissions threshold of 10,000 mtCO₂e. A wildfire of 18,940 acres would be required at an emissions threshold of 25,000 mtCO₂e, and a wildfire of 75,761 acres would be eligible for reporting under an emissions threshold of 100,000 mtCO₂e (Table 2).

N₂O and CH₄ combined: Assuming that both CH₄ and N₂O are released simultaneously during fire and a high forest C density of 300 tons C per ha, and using the highest emission factors reported in the literature, a wildfire of 82 acres would be eligible for entity reporting at the 1,000 mtCO₂e threshold level and a wildfire of 819 acres would be eligible at the 10,000 mtCO₂e threshold level. A wildfire of 2,047 acres would trigger the reporting requirement at the 25,000 mtCO₂e level, and a fire size of 8,190 acres would be reported under the 100,000 mtCO₂e threshold. Assuming the lowest emission factors for both N₂O and CH₄ and an average forest C density of 150 tons C per ha, the threshold sizes are much larger: 547 acres for the 1,000 mtCO₂e reporting threshold, 5,470 acres for the 10,000 mtCO₂e reporting threshold, 13,674 acres for the 25,000 mtCO₂e threshold and 54,697 acres for the 100,000 mtCO₂e threshold (Table 3).

Table 1. Threshold wildfire sizes under various reporting thresholds for N₂O emissions (acres).

	1,000 mtCO ₂ e	10,000 mtCO ₂ e	25,000 mtCO ₂ e	100,000 mtCO ₂ e
Highest emission factor, high forest C density	227	2,270	5,675	22,700
Lowest emission factor, average forest C density	1,967	19,673	49,184	196,734

Table 2. Threshold wildfire sizes under various reporting thresholds for CH₄ emissions (acres).

	1,000 mtCO ₂ e	10,000 mtCO ₂ e	25,000 mtCO ₂ e	100,000 mtCO ₂ e
Highest emission factor, high forest C	128	1,281	3,203	12,813

density				
Lowest emission factor, average forest C density	758	7,576	18,940	75,761

Table 3. Threshold wildfire sizes under various reporting thresholds for combined N₂O and CH₄ emissions (acres).

	1,000 mtCO ₂ e	10,000 mtCO ₂ e	25,000 mtCO ₂ e	100,000 mtCO ₂ e
Highest emission factor, high C density	82	819	2,047	8,190
Lowest emission factor, average C density	547	5,470	13,674	54,697

While fires larger than 400 ha (about 1000 acres) have historically been fairly infrequent in the United States, Westerling et al. (2006) reported a dramatic increase in these large fires over the last several decades. Between 2000 and 2003, between 50 and 100 such large wildfires burned annually in the Western states.

Existing Federal Data Collection Systems

There are no Federal monitoring programs for N₂O and CH₄ emissions from soils and vegetation in forests remaining forests. Data is available on a national level for “wildland area burned.” To complete national emissions estimates for this source, the forest proportion of wildland area must be approximated and extracted from this area data. There are no current systems that collect the data needed at the entity level for reporting of N₂O and CH₄ emissions from fire (fire severity, proportion of biomass burned per fire, aerial extent of fire).

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Other Land Use, Land-Use Change, and Forestry C Emissions and Sinks

In the *Inventory of U.S. Greenhouse Gas Emissions and Sinks*, the United States reports net greenhouse gas fluxes associated with IPCC designated land-use categories according to UNFCCC reporting guidelines and IPCC guidance. The carbon flux estimates included in the national GHG Inventory represent total net carbon stock changes on United States land areas. This net carbon stock change approach accounts for both gains and losses of forest carbon in the aboveground and belowground biomass, dead organic matter, and soil, as well as in durable wood products in use and in landfills. The net carbon stock changes reflect growth, mortality, harvesting, and other management activities, as well as increases and decreases in forest area. The approach used for the national GHG Inventory, therefore, implicitly accounts for carbon dioxide emissions due to disturbances such as forest fires. For more information on the magnitude of CO₂ emissions from forest fires in the United States, the *Inventory of U.S. Greenhouse Gas Emissions and Sinks*. Net carbon CO₂ flux reported in the GHG Inventory also includes C fluxes from croplands, grasslands, and settlements, and changes from one land use type to another. In the United States, the total net CO₂ flux from C stock changes in Land Use, Land-Use Change, and Forestry was 883.7 MMTCO₂ in 2006.

Monitoring

Land use-based accounting methods for quantifying CO₂ sources and sinks typically involve average C density and accumulation values for land use types (emission factors) applied to land areas categorized by type (activity data). Emission factors are developed at multiple scales and involve different levels of resolution depending on the datasets used to develop them. Often, average emission factors by region or vegetation type are developed and used (e.g. Smith et al. 2006).

At the national scale, the U.S. Forest Service Forest Inventory and Analysis (FIA) program collects data on forest area and management. Forest carbon stocks and net carbon stock changes are estimated by applying a collection of conversion factors and models, referred to as FORCARB2, to the tree and plot-level forest survey data collected through the FIA program.

For forest C accounting at the project and entity scales, the USDA Forest Service has developed look-up tables based on FIA data, which is available in a consistent format at the national scale. These look-up tables 1) quantify C stocks by age in “average” forest for a given region, stratified by forest type; and 2) directly estimate biomass using allometric approaches but indirectly estimate pools such as soil C, forest floor C, coarse woody debris, and understory C. Inventory datasets can provide useful activity data, though their data are most robust at the county scale, so there are limitations in tracking emissions from smaller-scale land conversion.

In the IPCC default methodology for land converted to settlements, the biomass in vegetation after land conversion is set to zero (IPCC 2006). Thus, for these forests the emission factor is essentially the C density in the standing forest prior to conversion. These default methods assume that 20% of soil C is also lost during forest conversion (IPCC 2006).

Land use conversions to cropland typically result in a net loss of C and N₂O from biomass and soils, though conversion of sparsely vegetated or highly degraded land to cropland may lead to a net C increase. As with settlements, in the IPCC default methodology for land converted to croplands the biomass in vegetation after conversion is set to zero (IPCC 2006). Year-to-year increases in woody biomass on cropland (orchards, vineyards, etc.) can be estimated using default emission factors, though no change in vegetation biomass occurs for annual crops (IPCC 2006). C stock changes on the majority of cropland

are typically a result of soil C gain or loss from the soil pool. The emission factors describing change in the soil C pool before and after conversion to cropland can indicate a net loss or a net increase of soil C, depending on the intensity of cultivation, the types of inputs used, and the climate regime in the area of interest (IPCC 2006).

Because grasslands “vary greatly in their degree and intensity of management, from extensively managed rangelands and savannahs – where animal stocking rates and fire regimes are the main management variables – to intensively managed (e.g., with fertilization, irrigation, species changes) continuous pasture and hay land” (IPCC 2006), it is even more difficult to generalize about the impacts of land conversion to this type. Depending on the land use prior to conversion, C may be gained or lost from the vegetation and soils. Prescribed fire may also contribute to the emissions due to land conversion to grassland (IPCC 2006).

Information to be Collected

The following information would need to be collected to monitor emissions using the IPCC methodology: land area converted, and forest and soil C density prior to land conversion.

Uncertainties

When large land areas are involved in land use change-based emissions monitoring, coarse estimates may be appropriate and even desirable. At the scale of individual reporters, accurate reporting of C gains and losses due to land use change could require reporters to report the amount of land use change along with estimates of emissions associated with the change. These estimates may be quite uncertain at the scale of individual reporters, especially if the land areas being considered are small or if there are deviations from standard management regimes. For individual reporters, the emissions factors and look-up tables that are readily available for assessment of forest C storage are not likely to reflect the variety of conditions that exist for a specific portion of the landscape. Similarly, for croplands, grasslands, and settlements, the management regimes before and after conversion are the main drivers of changes in C stocks for particular ownerships. Characterization of these changes requires site-specific information that is typically not available at the scale of individual reporters. Even for cases where such information is available, emissions factors are not expressed at a resolution fine enough to account for this site-level variability.

Reporters and Thresholds

Reporters could be real estate developers or investors, individuals with private land, land conservation organizations, governments, or other entities. Complicating the identification of reporters, and the reporting of emissions, is that a plot of land that exceeds an emissions threshold level one year may be a sink of emissions the next and vice versa.

The emission or storage of greenhouse gases in a land area is determined by the C density of the original forests or soils, management practices, any land conversion that occurs on that land, and the fate of the C and N in any cleared soil and vegetation. Developed land areas are quite heterogeneous and this will greatly impact the change in soil C and biomass C stocks as well as the mineralization of soil organic carbon and resulting N₂O emissions. As an example, there could be a hectare of grassland converted to a hectare of settlement area, which could include trees, a building, turf grass, a parking lot, ornamental plants, maybe even a pond. Soil C and biomass C could increase or decrease depending on the actual conversion implemented. This makes a threshold analysis for emissions from land use very difficult as there is great variation between land types and land use changes in the United States, and land areas can be either emissions sources or sinks.

To conduct a threshold analysis for this source, it would be necessary to estimate the emissions per unit land area in the United States. An estimate based on carbon flux nationally would result in net sequestration per acre and no land area would therefore meet or exceed the threshold. An estimate that uses IPCC default values for forest C density and the default assumption that forest clearing for development results in a complete loss of aboveground biomass due to decomposition would not provide information that could be used to assess the number of reporters or emission covered because it may overestimate carbon loss per unit of land. Either of these approaches is also complicated by the fact that management practices, vegetation, soils, etc., in any specific land area can vary greatly from year to year.

Existing Federal Data Collection Systems

Detailed, spatially-explicit activity data are available from a variety of sources at numerous spatial resolutions, including the National Land Cover Dataset (coarse resolution), the National Resource Inventory dataset (fine resolution), satellite imagery purchase by federal/state/local governments and organizations (varying resolution), or the National Agricultural Imagery Program (fine resolution). Many of these sources provide raw data that must be classified in order to be useful, yet classification is expensive, time-consuming, and often inaccurate.

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