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Inventory of U.S. Greenhouse Gas Emissions and Sinks:

1990 – 2011

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The assignment priority does not reflect the level of importance for reporting greenhouse gas emissions and removals on managed land, but is intended to classify all areas into a single land use. Currently, the IPCC does not make provisions in the guidelines for assigning land to multiple uses. For example, a Wetland is classified as Forest Land if the area has sufficient tree cover to meet the stocking and stand size requirements. Similarly, Wetlands are classified as Cropland if they are used for crop production, such as rice or cranberries. In either case, emissions from Wetlands are included in the Inventory if human interventions are influencing emissions from Wetlands, in accordance with the guidance provided in IPCC (2006).

Recalculations Discussion

Alaska was added to the latest inventory and a formal analysis was conducted for managed and unmanaged lands. Both improvements led to significant changes in the reporting of the managed land base. Overall more land area is incorporated into this Inventory, but a large portion of this land is designated as unmanaged due to the remoteness of some areas in Alaska.

In addition, new data were incorporated from FIA on forestland areas, which was used to make minor adjustments to the time series. FIA conducts a survey of plots annually so that each plot is visited every 5 years (Note: some states have not initiated the annual sampling regime, as discussed previously). Consequently, the time series is updated each year as new data are collected over the 5 year cycles.

Planned Improvements

Area data by land-use category are not estimated for the U.S. territories. A key planned improvement is to incorporate land-use data from these areas into the Inventory. Fortunately, most of the managed land in the United States is included in the current land-use statistics, but a complete accounting is a key goal for the near future. Data sources will also be evaluated for representing land use on federal and non-federal lands in U.S. territories.

Additional work will be conducted to reconcile differences in Forest Land estimates between the NRI and FIA, evaluating the assumption that the majority of discrepancies in Forest Land areas are associated with an over- or under-estimation of Grassland and Wetland area. In some regions of the United States, a discrepancy in Forest Land areas between NRI and FIA may be associated with an over- or under-prediction of other land uses, and an analysis is planned to develop region-specific adjustments.

There are also other databases that may need to be reconciled with the NRI and NLCD datasets, particularly for Settlements and Wetlands. Urban area estimates, used to produce C stock and flux estimates from urban trees, are currently based on population data (1990 and 2000 U.S. Census data). Using the population statistics, "urban clusters" are defined as areas with more than 500 people per square mile. The USFS is currently moving ahead with an urban forest inventory program so that urban forest area estimates will be consistent with FIA forest area estimates outside of urban areas, which would be expected to reduce omissions and overlap of forest area estimates along urban boundary areas.

The implementation criteria will also be expanded in the future, particularly in regard to inclusion of areas managed for mining and petroleum extraction. This criteria will have an impact on the managed land base in Alaska although there will still be large tracts of unmanaged land in this region with virtually no direct influence on GHG emissions from human activity.

7.2 Forest Land Remaining Forest Land

Changes in Forest Carbon Stocks (IPCC Source Category 5A1)

For estimating C stocks or stock change (flux), C in forest ecosystems can be divided into the following five storage pools (IPCC 2003):

- Aboveground biomass, which includes all living biomass above the soil including stem, stump, branches, bark, seeds, and foliage. This category includes live understory.
- Belowground biomass, which includes all living biomass of coarse living roots greater than 2 mm diameter.
- Dead wood, which includes all non-living woody biomass either standing, lying on the ground (but not including litter), or in the soil.
- Litter, which includes the litter, fumic, and humic layers, and all non-living biomass with a diameter less than 7.5 cm at transect intersection, lying on the ground.
- Soil organic C (SOC), including all organic material in soil to a depth of 1 meter but excluding the coarse roots of the aboveground pools.

In addition, there are two harvested wood pools necessary for estimating C flux:

- Harvested wood products (HWP) in use.
- HWP in solid waste disposal sites (SWDS).

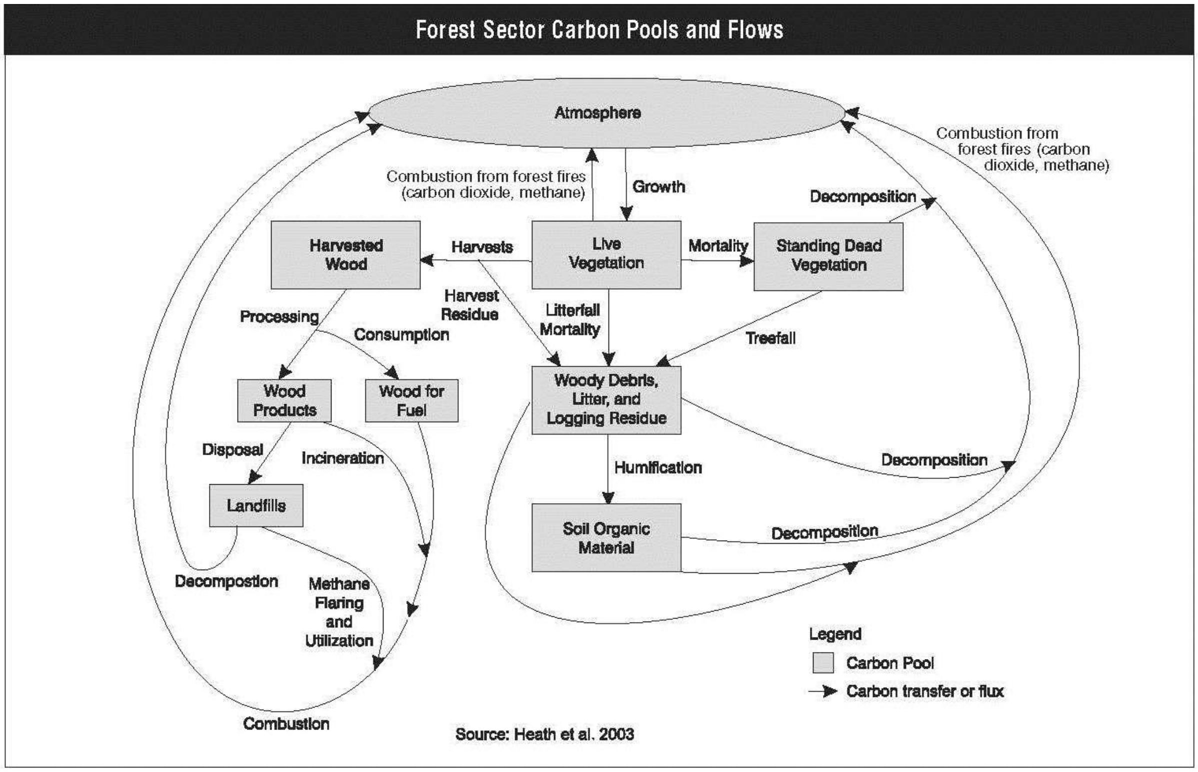
Carbon is continuously cycled among these storage pools and between forest ecosystems and the atmosphere as a result of biological processes in forests (e.g., photosynthesis, respiration, growth, mortality, decomposition, and disturbances such as fires or pest outbreaks) and anthropogenic activities (e.g., harvesting, thinning, clearing, and replanting). As trees photosynthesize and grow, C is removed from the atmosphere and stored in living tree biomass. As trees die and otherwise deposit litter and debris on the forest floor, C is released to the atmosphere and also is transferred to the soil by organisms that facilitate decomposition.

The net change in forest C is not equivalent to the net flux between forests and the atmosphere because timber harvests do not cause an immediate flux of C of all vegetation C to the atmosphere. Instead, harvesting transfers a portion of the C stored in wood to a "product pool." Once in a product pool, the C is emitted over time as CO_2 when the wood product combusts or decays. The rate of emission varies considerably among different product pools. For example, if timber is harvested to produce energy, combustion releases C immediately. Conversely, if timber is harvested and used as lumber in a house, it may be many decades or even centuries before the lumber decays and C is released to the atmosphere. If wood products are disposed of in SWDS, the C contained in the wood may be released many years or decades later, or may be stored almost permanently in the SWDS.

This section quantifies the net changes in C stocks in the five forest C pools and two harvested wood pools. The net change in stocks for each pool is estimated, and then the changes in stocks are summed over all pools to estimate total net flux. The focus on C implies that all C-based greenhouse gases are included, and the focus on stock change suggests that specific ecosystem fluxes do not need to be separately itemized in this report. Changes in C stocks from disturbances, such as forest fires, are implicitly included in the net changes. For instance, an inventory conducted after fire counts only the trees that are left. The change between inventories thus accounts for the C changes due to fires; however, it may not be possible to attribute the changes to the disturbance specifically. Similarly, changes in C stocks from natural disturbances, such as wildfires, pest outbreaks, and storms, are implicitly accounted for in the forest inventory approach; however, they are highly variable from year to year. Wildfire events are typically the most severe but other natural disturbance events can result in large C stock losses that are time- and location- specific. The IPCC (2003) recommends reporting C stocks according to several land-use types and conversions, specifically *Forest Land Remaining Forest Land* and *Land Converted to Forest Land*. Currently, consistent datasets are just becoming available for the conterminous United States to allow forest land conversions and forest land remaining forest land to be identified, and research is ongoing to properly use that information based on research results. Thus, net changes in all forest-related land, including non-forest land converted to forest and forests converted to non-forest, are reported here.

Forest C storage pools, and the flows between them via emissions, sequestration, and transfers, are shown in Figure 7-2. In the figure, boxes represent forest C storage pools and arrows represent flows between storage pools or between storage pools and the atmosphere. Note that the boxes are not identical to the storage pools identified in this chapter. The storage pools identified in this chapter have been refined in this graphic to better illustrate the processes that result in transfers of C from one pool to another, and emissions to as well as uptake from the atmosphere.

Figure 7-2: Forest Sector Carbon Pools and Flows



Approximately 33 percent (304 million hectares) of the U.S. land area is forested (Smith et al. 2009). The current forest C inventory includes 275 million hectares in the conterminous 48 states (USDA Forest Service 2012a, 2012b) that are considered managed and are included in this inventory. An additional 6 million hectares of southeast and south central Alaskan forest are inventoried and are included here. Some differences exist in forest land defined in Smith et al. (2009) and the forest land included in this report, which is based on USDA Forest Service (2012b). Survey data are not yet available from Hawaii and a large portion of interior Alaska, but estimates of these areas are included in Smith et al. (2009). Alternately, updated survey data for central and western forest land in both Oklahoma and Texas have only recently become available, and these forests contribute to overall C stock reported below. While Hawaii and U.S. territories have relatively small areas of forest land and will thus probably not influence the overall C budget substantially, these regions will be added to the C budget as sufficient data become available. Agroforestry systems are also not currently accounted for in the inventory, since they are not explicitly inventoried by either the FIA program of USDA Forest Service or the NRI of the USDA Natural Resources Conservation Service (Perry et al. 2005).

Sixty-eight percent (208 million hectares) of U.S. forests in Alaska and the conterminous U.S. are classified as timberland, meaning they meet minimum levels of productivity and have not been removed from production. Nine percent of Alaskan forests and 81 percent of forests in the conterminous United States are classified as timberlands. Of the remaining nontimberland forests, 30 million hectares are reserved forest lands (withdrawn by law from management for production of wood products) and 66 million hectares are lower productivity forest lands (Smith et al. 2009). Historically, the timberlands in the conterminous 48 states have been more frequently or intensively surveyed than other forest lands.

Forest land area declined by approximately 10 million hectares over the period from the early 1960s to the late 1980s. Since then, forest area has increased by about 12 million hectares (Smith et al. 2009). Current trends in forest area represent an average annual increase of 0.2 percent. In addition to the increase in forest area, the major influences on the current net C flux from forest land are management activities and the ongoing impacts of previous land-use changes. These activities affect the net flux of C by altering the amount of C stored in forest ecosystems. For example, intensified management of forests that leads to an increased rate of growth increases the eventual biomass density of the forest, thereby increasing the uptake of C.[226] Though harvesting forests removes much of the aboveground C, on average the volume of annual net growth nationwide is about 72 percent higher than the volume of annual removals on timberlands (Smith et al. 2009). The reversion of cropland to forest land increases C storage in biomass, forest floor, and soils. The net effects of forest management and the effects of land-use change involving forest land are captured in the estimates of C stocks and fluxes presented in this chapter.

In the United States, improved forest management practices, the regeneration of previously cleared forest areas, and timber harvesting and use have resulted in net uptake (i.e., net sequestration) of C each year from 1990 through 2011. The rate of forest clearing begun in the 17th century following European settlement had slowed by the late 19th century. Through the later part of the 20th century many areas of previously forested land in the United States were allowed to revert to forests or were actively reforested. The impacts of these land-use changes still influence C fluxes from these forest lands. More recently, the 1970s and 1980s saw a resurgence of federally-sponsored forest management programs (e.g., the Forestry Incentive Program) and soil conservation programs (e.g., the Conservation Reserve Program), which have focused on tree planting, improving timber management activities, combating soil erosion, and converting marginal cropland to forests. In addition to forest regeneration and management, forest harvests have also affected net C fluxes. Because most of the timber harvested from U.S. forests is used in wood products, and many discarded wood products are disposed of in SWDS rather than by incineration, significant quantities of C in harvested wood are transferred to long-term storage pools rather than being released rapidly to the atmosphere (Skog and Nicholson 1998, Skog 2008). The size of these long-term C storage pools has increased during the last century.

Changes in C stocks in U.S. forests and harvested wood were estimated to account for net sequestration of 834 Tg CO_2 Eq. (227 Tg C) in 2011 (Table 7-7, Table 7-8, and Table 7-9). In addition to the net accumulation of C in harvested wood pools, sequestration is a reflection of net forest growth and increasing forest area over this period. Overall, average C in forest ecosystem biomass (aboveground and belowground) increased from 54 to 62 Mg C/ha between 1990 and 2012 (see Annex 3-12 for average C densities by specific regions and forest types). Continuous, regular annual surveys are not available over the period for each state; therefore, estimates for non-survey years were derived by interpolation between known data points. Survey years vary from state to state, and national estimates are a composite of individual state surveys. Therefore, changes in sequestration over the interval 1990 to 2011 are the result of the sequences of new inventories for each state. C in forest ecosystem biomass had the greatest effect on total change through increases in C density and total forest land. Management practices that increase C stocks on forest land, as well as afforestation and reforestation efforts, influence the trends of increased C densities in forests and increased forest land in the United States.

Annual net additions to HWP carbon stock were estimated to continue to increase during 2011 from a low in 2009 as inputs to products in use for both solid wood and paper products increased with continued recovery from the recession. Gross inputs to products in use in 2011 were well above the discard rate but net additions to products in use were still about 25 percent below the rate for 2008. The primary reason for overall net additions in recent years is a near stable rate of net additions to products in landfills. Estimates of C additions for 2008, 2009 and 2010 were adjusted downward due to revision in data on softwood pulpwood production, hardwood lumber production, hardwood plywood production, and imports of particleboard and medium density fiberboard. Due to the change in import data, estimates of C storage were reduced more for the Stock Change Accounting approach (Annex Table A-228) than the Production Approach (Table 7-7, Annex Table A-228).

Table 7-7: Net Annual Changes in C Stocks (Tg CO_2/yr) in Forest and Harvested Wood Pools

Carbon Pool	1990		2005		2007	2008	2009	2010	2011
Forest	**(565.1)**		**(799.6)**		**(757.0)**	**(757.1)**	**(757.1)**	**(758.2)**	**(761.8)**
Aboveground Biomass	(359.8)		(436.4)		(404.0)	(403.9)	(403.9)	(403.9)	(403.9)
Belowground Biomass	(70.3)		(86.0)		(80.1)	(80.1)	(80.1)	(80.1)	(80.1)
Dead Wood	(32.6)		(47.1)		(52.3)	(52.3)	(52.3)	(53.4)	(57.1)

226 The term "biomass density" refers to the mass of live vegetation per unit area. It is usually measured on a dry-weight basis. Dry biomass is 50 percent C by weight.

Litter	(25.0)		(49.6)		(54.5)	(54.5)	(54.5)	(54.5)	(54.5)
Soil Organic Carbon	(77.4)		(180.5)		(166.2)	(166.3)	(166.3)	(166.3)	(166.3)
Harvested Wood	**(131.8)**		**(105.4)**		**(102.3)**	**(76.3)**	**(54.3)**	**(59.4)**	**(71.7)**
Products in Use	(64.8)		(45.4)		(38.5)	(13.6)	6.8	1.2	(10.0)
SWDS	(67.0)		(59.9)		(63.8)	(62.7)	(61.0)	(60.7)	(61.7)
Total Net Flux	**(696.8)**		**(905.0)**		**(859.3)**	**(833.3)**	**(811.3)**	**(817.6)**	**(833.5)**

Note: Forest C stocks do not include forest stocks in U.S. territories, Hawaii, a portion of managed forests in Alaska, or trees on non-forest land (e.g., urban trees, agroforestry systems). Parentheses indicate net C sequestration (i.e., a net removal of C from the atmosphere). Total net flux is an estimate of the actual net flux between the total forest C pool and the atmosphere. Forest area estimates are based on interpolation and extrapolation of inventory data as described in the text and in Annex 3.12. Harvested wood estimates are based on results from annual surveys and models. Totals may not sum due to independent rounding.

Table 7-8: Net Annual Changes in C Stocks (Tg C/yr) in Forest and Harvested Wood Pools

Carbon Pool	1990		2005		2007	2008	2009	2010	2011
Forest	**(154.1)**		**(218.1)**		**(206.5)**	**(206.5)**	**(206.5)**	**(206.8)**	**(207.8)**
Aboveground Biomass	(98.1)		(119.0)		(110.2)	(110.2)	(110.2)	(110.2)	(110.2)
Belowground Biomass	(19.2)		(23.4)		(21.8)	(21.8)	(21.8)	(21.8)	(21.8)
Dead Wood	(8.9)		(12.9)		(14.3)	(14.3)	(14.3)	(14.6)	(15.6)
Litter	(6.8)		(13.5)		(14.9)	(14.9)	(14.9)	(14.9)	(14.9)
Soil Organic C	(21.1)		(49.2)		(45.3)	(45.4)	(45.4)	(45.4)	(45.4)
Harvested Wood	**(35.9)**		**(28.7)**		**(28.1)**	**(20.8)**	**(14.8)**	**(16.2)**	**(19.5)**
Products in Use	(17.7)		(12.4)		(10.5)	(3.7)	1.8	0.3	(2.7)
SWDS	(18.3)		(16.3)		(17.4)	(17.1)	(16.6)	(16.5)	(16.8)
Total Net Flux	**(190.0)**		**(246.8)**		**(234.4)**	**(227.3)**	**(221.3)**	**(223.0)**	**(227.3)**

Note: Forest C stocks do not include forest stocks in U.S. territories, Hawaii, a portion of managed lands in Alaska, or trees on non-forest land (e.g., urban trees, agroforestry systems). Parentheses indicate net C sequestration (i.e., a net removal of C from the atmosphere). Total net flux is an estimate of the actual net flux between the total forest C pool and the atmosphere. Harvested wood estimates are based on results from annual surveys and models. Totals may not sum due to independent rounding.

Stock estimates for forest and harvested wood C storage pools are presented in Table 7-9. Together, the aboveground live and forest soil pools account for a large proportion of total forest C stocks. C stocks summed for non-soil pools increased over time Figure 7-3. Therefore, C sequestration was greater than C emissions from forests, as discussed above. Figure 7-4 shows county-average C densities for live trees on forest land, including both above- and belowground biomass.

Table 7-9: Forest area (1000 ha) and C Stocks (Tg C) in Forest and Harvested Wood Pools

	1990		2005		2007	2008	2009	2010	2011
Forest Area (1000 ha)	**271,794**		**279,781**		**281,090**	**281,694**	**282,300**	**282,905**	**283,510**
Carbon Pools (Tg C)									
Forest	**38,777**		**41,192**		**41,618**	**41,825**	**42,031**	**42,238**	**42,444**
Aboveground Biomass	12,284		13,912		14,146	14,256	14,366	14,476	14,586
Belowground Biomass	2,432		2,752		2,798	2,820	2,842	2,863	2,885
Dead Wood	2,161		2,342		2,368	2,383	2,397	2,411	2,426
Litter	4,816		4,880		4,908	4,923	4,937	4,952	4,967
Soil Organic C	17,084		17,306		17,399	17,444	17,489	17,535	17,580
Harvested Wood	**1,859**		**2,325**		**2,383**	**2,411**	**2,432**	**2,447**	**2,463**

Products in Use	1,231	1,436	1,460	1,471	1,474	1,472	1,472
SWDS	628	890	923	941	958	974	991
Total C Stock	**40,637**	**43,517**	**44,002**	**44,236**	**44,463**	**44,684**	**44,907**

Note: Forest area estimates include portions of managed forests in Alaska for which survey data are available. Forest C stocks do not include forest stocks in U.S. territories, Hawaii, a large portion of Alaska, or trees on non-forest land (e.g., urban trees, agroforestry systems). Wood product stocks include exports, even if the logs are processed in other countries, and exclude imports. Forest area estimates are based on interpolation and extrapolation of inventory data as described in Smith et al. (2010) and in Annex 3.12. Harvested wood estimates are based on results from annual surveys and models. Totals may not sum due to independent rounding. Inventories are assumed to represent stocks as of January 1 of the inventory year. Flux is the net annual change in stock. Thus, an estimate of flux for 2006 requires estimates of C stocks for 2006 and 2007.

Figure 7-3: Estimates of Net Annual Changes in C Stocks for Major C Pools

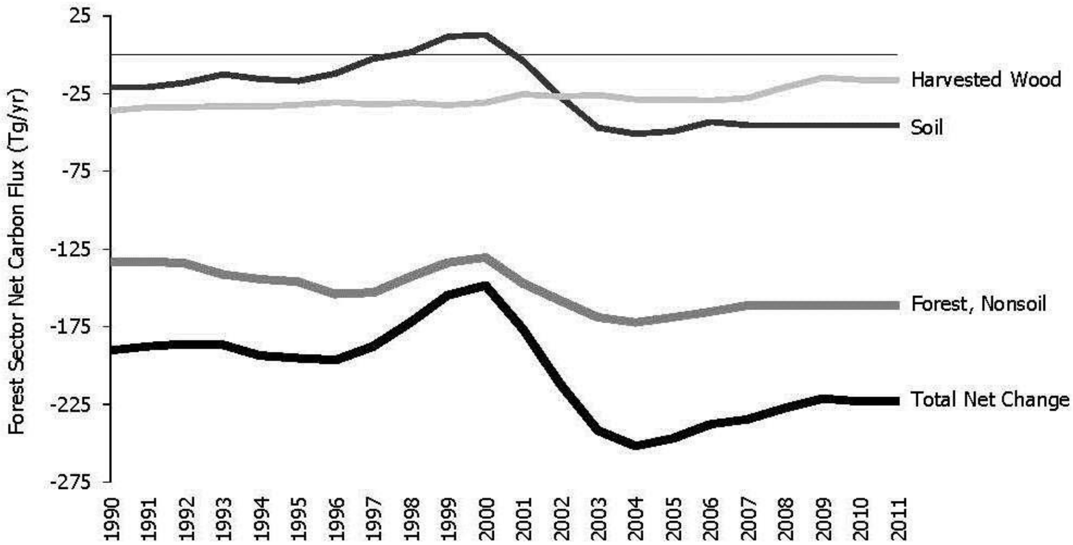
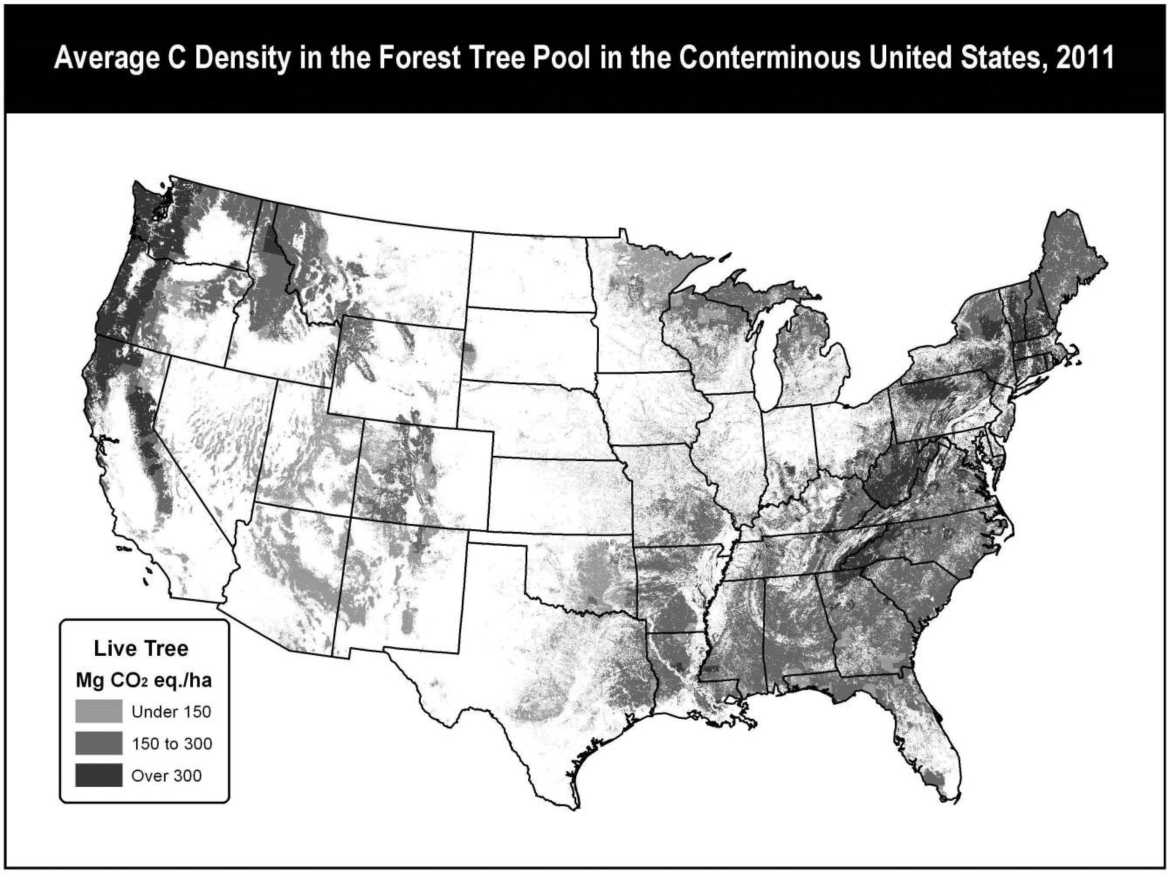


Figure 7-4: Average C Density in the Forest Tree Pool in the Conterminous United States, 2010



Box 7-2: CO_2 Emissions from Forest Fires

As stated previously, the forest inventory approach implicitly accounts for emissions due to disturbances such as forest fires, because only C remaining in the forest is estimated. Net C stock change is estimated by subtracting consecutive C stock estimates. A forest fire disturbance removes C from the forest. The inventory data on which net C stock estimates are based already reflect this C loss. Therefore, estimates of net annual changes in C stocks for U.S. forestland already account for CO_2 emissions from forest fires occurring in the lower 48 states as well as in the proportion of Alaska's managed forest land captured in this Inventory. Because it is of interest to quantify the magnitude of CO_2 emissions from fire disturbance, these estimates are highlighted here, using the full extent of available data. Non-CO_2 greenhouse gas emissions from forest fires are also quantified in a separate section below.

The IPCC (2003) methodology and IPCC (2006) default combustion factor for wildfire were employed to estimate CO_2 emissions from forest fires. CO_2 emissions for wildfires and prescribed fires in the lower 48 states and wildfires in Alaska in 2011 were estimated to be 225.3 Tg CO_2/yr. This amount is masked in the estimate of net annual forest C stock change for 2011 because this net estimate accounts for the amount sequestered minus any emissions.

Table 7-10: Estimates of CO_2 (Tg/yr) Emissions for the Lower 48 States and Alaska[a]

Year	CO_2 emitted from Wildfires in Lower 48 States (Tg/yr)	CO_2 emitted from Prescribed Fires in Lower 48 States (Tg/yr)	CO_2 emitted from Wildfires in Alaska (Tg/yr)	Total CO_2 emitted (Tg/yr)
1990	32.4	7.1	+	39.5
2005	107.0	20.7	+	127.7
2007	203.5	24.8	+	228.3
2008	122.5	15.3	+	137.8
2009	70.6	20.1	+	90.6
2010	54.9	19.3	+	74.2
2011	208.0	17.3	+	225.3

+ Does not exceed 0.05 Tg CO_2 Eq.

[a] Note that these emissions have already been accounted for in the estimates of net annual changes in C stocks, which account for the amount sequestered minus any emissions.

Methodology and Data Sources

The methodology described herein is consistent with IPCC (2003, 2006) and IPCC/UNEP/OECD/IEA (1997). Forest ecosystem C stocks and net annual C stock change were determined according to stock-difference methods, which involved applying C estimation factors to forest inventory data and interpolating between successive inventory-based estimates of C stocks. Harvested wood C estimates were based on factors such as the allocation of wood to various primary and end-use products as well as half-life (the time at which half of the amount placed in use will have been discarded from use) and expected disposition (e.g., product pool, SWDS, combustion). An overview of the different methodologies and data sources used to estimate the C in forest ecosystems or harvested wood products is provided here. See Annex 3.12 for details and additional information related to the methods and data.

Forest Ecosystem Carbon from Forest Inventory

Forest ecosystem stock and flux estimates are based on the stock-difference method and calculations for all estimates are in units of C. Separate estimates were made for the five IPCC C storage pools described above. All estimates were based on data collected from the extensive array of permanent forest inventory plots in the United States as well as models employed to fill gaps in field data (USDA Forest Service 2012b, 2012c). Carbon conversion factors were applied at the disaggregated level of each inventory plot and then appropriately expanded to population estimates. A combination of tiers as outlined by IPCC (2006) was used. The Tier 3 biomass C values were calculated from forest inventory tree-level data. The Tier 2 dead organic and soil C pools were based on empirical or process models from the inventory data. All C conversion factors are specific to regions or individual states within the United States, which were further classified according to characteristic forest types within each region.

The first step in developing forest ecosystem estimates is to identify useful inventory data and resolve any inconsistencies among datasets. Forest inventory data were obtained from the FIA program (Frayer and Furnival 1999, USDA Forest Service 2012b). Inventories include data collected on permanent inventory plots on forest lands and were organized as a number of separate datasets, each representing a complete inventory, or survey, of an individual state at a specified time.[227] Many of the more recent annual inventories reported for states were

[227] Forest land in the United States includes land that is at least 10 percent stocked with trees of any size. Timberland is the most productive type of forest land, which is on unreserved land and is producing or capable of producing crops of industrial wood.

represented as "moving window" averages, which means that a portion—but not all—of the previous year's inventory is updated each year (USDA Forest Service 2012d). Forest C calculations were organized according to these state surveys, and the frequency of surveys varies by state. All available data sets were identified for each state starting with pre-1990 data, and all unique surveys were identified for stock and change calculations. Since C stock change is based on differences between successive surveys within each state, accurate estimates of net C flux thus depend on consistent representation of forest land between these successive inventories. In order to achieve this consistency from 1990 to the present, states were sometimes subdivided into sub-state areas where the sum of sub-state inventories produces the best whole-state representation of C change as discussed in Smith et al. (2010).

The principal FIA datasets employed are freely available for download at USDA Forest Service (2012b) as the Forest Inventory and Analysis Database (FIADB) Version 5.1 (USDA Forest Service 2012, Woudenberg et al. 2010). However, to achieve consistent representation (spatial and temporal), three other general sources of past FIA data were included as necessary. First, older FIA plot- and tree-level data—not in the current FIADB format—were used if available. Second, Resources Planning Act Assessment (RPA) databases, which are periodic, plot-level only, summaries of state inventories, were used to provide the data at or before 1990. Finally, an additional forest inventory data source used was the Integrated Database (IDB), which is a compilation of periodic forest inventory data from the 1990s for California, Oregon, and Washington (Waddell and Hiserote 2005). These IDB data were identified by Heath et al. (2011) as the most appropriate non-FIADB sources for these states and were included in this inventory. See USDA Forest Service (2012a) for information on current and older data as well as additional FIA Program features. A detailed list of the specific forest inventory data used in this inventory is in Annex 3.12.

Forest C stocks were estimated from inventory data by a collection of conversion factors and models (Birdsey and Heath 1995, Birdsey and Heath 2001, Heath et al. 2003, Smith et al. 2004, Smith et al. 2006), which have been formalized in an FIADB-to-C calculator (Smith et al. 2010). The conversion factors and model coefficients were categorized by region and forest type, and forest C stock estimates were calculated from application of these factors at the scale of FIA inventory plots. The results were estimates of C density (Mg C per hectare) for six forest ecosystem pools: live trees, standing dead trees, understory vegetation, down dead wood, forest floor, and soil organic matter. The six C pools used in the FIADB-to-C calculator were aggregated to the 5 C pools defined by IPCC (2006): aboveground biomass, belowground biomass, dead wood, litter, and soil organic matter. The live-tree and understory C were pooled as biomass, and standing dead trees and down dead wood were pooled as dead wood, in accordance with IPCC (2006).

Once plot-level C stocks were calculated as C densities on *Forest Land Remaining Forest Land* for the five IPCC (2006) reporting pools, the stocks were expanded to population estimates according to methods appropriate to the respective inventory data (for example, see Bechtold and Patterson (2005)). These expanded C stock estimates were summed to state or sub-state total C stocks. Annualized estimates of C stocks were developed by using available FIA inventory data and interpolating or extrapolating to assign a C stock to each year in the 1990 through 2012 time series. Flux, or net annual stock change, was estimated by calculating the difference in stocks between two successive years and applying the appropriate sign convention; net increases in ecosystem C were identified as negative flux. By convention, inventories were assigned to represent stocks as of January 1 of the inventory year; an estimate of flux for 1996 required estimates of C stocks for 1996 and 1997, for example. Additional discussion of the use of FIA inventory data and the C conversion process is in Annex 3.12.

Carbon in Biomass

Live tree C pools include aboveground and belowground (coarse root) biomass of live trees with diameter at diameter breast height (dbh) of at least 2.54 cm at 1.37 m above the forest floor. Separate estimates were made for above- and below-ground biomass components. If inventory plots included data on individual trees, tree C was based on Woodall et al. (2011a), which is also known as the component ratio method (CRM), and is a function of volume, species, and diameter. An additional component of foliage, which was not explicitly included in Woodall et al. (2011a), was added to each tree following the same CRM method. Some of the older forest inventory data in use for these estimates did not provide measurements of individual trees. Examples of these data include plots with incomplete or missing tree data or the RPA plot-level summaries. The C estimates for these plots were based on average densities (metric tons C per hectare) obtained from plots of more recent surveys with similar stand characteristics and location. This applies to 5 percent of the forest land inventory-plot-to-C conversions within the 183 state-level surveys utilized here.

Understory vegetation is a minor component of biomass, which is defined as all biomass of undergrowth plants in a forest, including woody shrubs and trees less than 2.54 cm dbh. In the current inventory, it was assumed that 10 percent of total understory C mass is belowground. Estimates of C density were based on information in Birdsey (1996) and biomass estimates from Jenkins et al. (2003). Understory frequently represented over 1 percent of C in biomass, but its contribution rarely exceeded 2 percent of the total.

Carbon in Dead Organic Matter

Dead organic matter was initially calculated as three separate pools—standing dead trees, down dead wood, and litter—with C stocks estimated from sample data or modeled. The standing dead tree C pools include aboveground and belowground (coarse root) mass and include trees of at least 12.7 cm dbh. Calculations followed the basic method applied to live trees (Woodall et al. 2011a) with additional modifications to account for decay and structural loss (Domke et al. 2011, Harmon et al. 2011). Similar to the situation with live tree data, some of the older forest inventory data did not provide sufficient data on standing dead trees to make accurate population-level estimates. The C estimates for these plots were based on average densities (metric tons C per hectare) obtained from plots of more recent surveys with similar stand characteristics and location. This applied to 25 percent of the forest land inventory-plot-to-C conversions within the 183 state-level surveys utilized here. Down dead wood estimates are based on measurement of a subset of FIA plots for downed dead wood(Domke et al., Woodall and Monleon 2008, Woodall et al. In Review). Down dead wood is defined as pieces of dead wood greater than 7.5 cm diameter, at transect intersection, that are not attached to live or standing dead trees. This includes stumps and roots of harvested trees. To facilitate the downscaling of downed dead wood C estimates from state to individual plots, downed dead wood models specific to regions and forest types within each region are used. Litter C is the pool of organic C (also known as duff, humus, and fine woody debris) above the mineral soil and includes woody fragments with diameters of up to 7.5 cm. Estimates are based on equations of Smith and Heath (2002).

Carbon in Forest Soil

Soil organic C includes all organic material in soil to a depth of 1 meter but excludes the coarse roots of the biomass or dead wood pools. Estimates of SOC were based on the national STATSGO spatial database (USDA 1991), which includes region and soil type information. SOC determination was based on the general approach described by Amichev and Galbraith (2004). Links to FIA inventory data were developed with the assistance of the USDA Forest Service FIA Geospatial Service Center by overlaying FIA forest inventory plots on the soil C map. This method produced mean SOC densities stratified by region and forest type group. It did not provide separate estimates for mineral or organic soils but instead weighted their contribution to the overall average based on the relative amount of each within forest land. Thus, forest SOC is a function of species and location, and net change also depends on these two factors as total forest area changes. In this respect, SOC provides a country-specific reference stock for 1990-present, but it does not reflect effects of past land use.

Harvested Wood Carbon

Estimates of the HWP contribution to forest C sinks and emissions (hereafter called "HWP Contribution") were based on methods described in Skog (2008) using the WOODCARB II model. These methods are based on IPCC (2006) guidance for estimating HWP C. IPCC (2006) provides methods that allow Parties to report HWP Contribution using one of several different accounting approaches: production, stock change and atmospheric flow, as well as a default method that assumes there is no change in HWP C stocks (see Annex 3.12 for more details about each approach). The United States used the production accounting approach to report HWP Contribution. Under the production approach, C in exported wood was estimated as if it remains in the United States, and C in imported wood was not included in inventory estimates. Though reported U.S. HWP estimates are based on the production approach, estimates resulting from use of the two alternative approaches, the stock change and atmospheric flow approaches, are also presented for comparison (see Annex 3.12). Annual estimates of change were calculated by tracking the additions to and removals from the pool of products held in end uses (i.e., products in use such as housing or publications) and the pool of products held in solid waste disposal sites (SWDS).

Solidwood products added to pools include lumber and panels. End-use categories for solidwood include single and multifamily housing, alteration and repair of housing, and other end-uses. There is one product category and one end-use category for paper. Additions to and removals from pools were tracked beginning in 1900, with the exception that additions of softwood lumber to housing began in 1800. Solidwood and paper product production and trade data were taken from USDA Forest Service and other sources (Hair and Ulrich 1963; Hair 1958; USDC Bureau of Census; 1976; Ulrich, 1985, 1989; Steer 1948; AF&PA 2006a 2006b; Howard 2003, 2007). Estimates for disposal of products reflected the change over time in the fraction of products discarded to SWDS (as opposed to burning or recycling) and the fraction of SWDS that were in sanitary landfills versus dumps.

There are five annual HWP variables that were used in varying combinations to estimate HWP Contribution using any one of the three main approaches listed above. These are:

(1A) annual change of C in wood and paper products in use in the United States,

(1B) annual change of C in wood and paper products in SWDS in the United States,

(2A) annual change of C in wood and paper products in use in the United States and other countries where the wood came from trees harvested in the United States,

(2B) annual change of C in wood and paper products in SWDS in the United States and other countries where the wood came from trees harvested in the United States,

(3) C in imports of wood, pulp, and paper to the United States,

(4) C in exports of wood, pulp and paper from the United States, and

(5) C in annual harvest of wood from forests in the United States.

The sum of variables 2A and 2B yielded the estimate for HWP Contribution under the production accounting approach. A key assumption for estimating these variables was that products exported from the United States and held in pools in other countries have the same half-lives for products in use, the same percentage of discarded products going to SWDS, and the same decay rates in SWDS as they would in the United States.

Uncertainty and Time Series Consistency

A quantitative uncertainty analysis placed bounds on current flux for forest ecosystems as well as C in harvested wood products through Monte Carlo Stochastic Simulation of the Methods described above and probabilistic sampling of C conversion factors and inventory data. See Annex 3.12 for additional information. The 2011 net annual change for forest C stocks was estimated to be between -957 and -712 Tg CO_2 Eq. at a 95 percent confidence level. This includes a range of -883.7 to -641.1 Tg CO_2 Eq. in forest ecosystems and -90.9 to -54.8 Tg CO_2 Eq. for HWP.

Table 7-11: Tier 2 Quantitative Uncertainty Estimates for Net CO_2 Flux from Forest Land Remaining Forest Land: Changes in Forest C Stocks (Tg CO_2 Eq. and Percent)

Source	Gas	2011 Flux Estimate (Tg CO_2 Eq.)	Uncertainty Range Relative to Flux Estimate [a] (Tg CO_2 Eq.)		(%)	
			Lower Bound	Upper Bound	Lower Bound	Upper Bound
Forest Ecosystem	CO_2	(761.8)	(883.7)	(641.1)	-16.0	+15.8
Harvested Wood Products	CO_2	(71.7)	(90.9)	(54.8)	-26.8	+23.6
Total Forest	**CO_2**	**(833.5)**	**(956.5)**	**(712.1)**	**-14.8**	**+14.6**

Note: Parentheses indicate negative values or net sequestration.
[a] Range of flux estimates predicted by Monte Carlo stochastic simulation for a 95 percent confidence interval.

Methodological recalculations were applied to the entire time-series to ensure time-series consistency from 1990 through 2011. Details on the emission trends through time are described in more detail in the Methodology section, above.

QA/QC and Verification

As discussed above, the FIA program has conducted consistent forest surveys based on extensive statistically-based sampling of most of the forest land in the conterminous United States, dating back to 1952. The FIA program includes numerous quality assurance and quality control (QA/QC) procedures, including calibration among field crews, duplicate surveys of some plots, and systematic checking of recorded data. Because of the statistically-based sampling, the large number of survey plots, and the quality of the data, the survey databases developed by the FIA program form a strong foundation for C stock estimates. Field sampling protocols, summary data, and detailed inventory databases are archived and are publicly available on the Internet (USDA Forest Service 2012d).

Many key calculations for estimating current forest C stocks based on FIA data were developed to fill data gaps in assessing forest C and have been in use for many years to produce national assessments of forest C stocks and stock changes (see additional discussion and citations in the Methodology section above and in Annex 3.12). General quality control procedures were used in performing calculations to estimate C stocks based on survey data. For example, the derived C datasets, which include inventory variables such as areas and volumes, were compared to standard inventory summaries such as the forest resource statistics of Smith et al. (2009) or selected population estimates generated from FIADB 5.1, which are available at an FIA internet site (USDA Forest Service 2012b). Agreement between the C datasets and the original inventories is important to verify accuracy of the data used. Finally, C stock estimates were compared with previous inventory report estimates to ensure that any differences could be explained by either new data or revised calculation methods (see the "Recalculations" discussion, below).

Estimates of the HWP variables and the HWP contribution under the production accounting approach use data from U.S. Census and USDA Forest Service surveys of production and trade. Factors to convert wood and paper to units C are based on estimates by industry and Forest Service published sources. The WOODCARB II model uses estimation methods suggested by IPCC (2006). Estimates of annual C change in solid wood and paper products in use were calibrated to meet two independent criteria. The first criterion is that the WOODCARB II model estimate of C in houses standing in 2001 needs to match an independent estimate of C in housing based on U.S. Census and USDA Forest Service survey data. Meeting the first criterion resulted in an estimated half-life of about 80 years for single family housing built in the 1920s, which is confirmed by other U.S. Census data on housing. The second criterion is that the WOODCARB II model estimate of wood and paper being discarded to SWDS needs to match EPA estimates of discards each year over the period 1990 to 2000 (EPA 2006). These criteria help reduce uncertainty in estimates of annual change in C in products in use in the United States and, to a lesser degree, reduce uncertainty in estimates of annual change in C in products made from wood harvested in the United States. In addition, WOODCARB II landfill decay rates have been validated by ensuring that estimates of CH_4 emissions from landfills based on EPA (2006) data are reasonable in comparison with CH_4 estimates based on WOODCARB II landfill decay rates.

Recalculations Discussion

In addition to annual updates to most-recent inventories for many states, four additional changes in method or data reduction for the current Inventory affected the national stock and change estimates for forest ecosystems. Of these, the modification of the down dead wood estimates to incorporate plot level sampling of down woody material (Woodall et al. 2010, Woodall et al. In Review) resulted in the greatest impact on total forest C stocks. Nationally, estimates for C in down dead wood stocks decreased by about 8 percent. A second change was a modification in the approach to determining the necessary volumes as inputs to the tree biomass equations, which only affected a few of the periodic (i.e., older) inventories. Next, we identified that the older forest inventories classified as woodlands on National Forests in Colorado included a spatial extent substantially lower than current inventories of that classification. The older inventories were dropped from our calculations because of the inconsistency (see annex 3.12 for specifics of inventories in use). Finally, the current FIADB 5.1 data do not include the periodic survey for Alaska as was included in the previous Inventory (EPA 2012). Therefore we retained the estimates based on FIADB 4.0after making appropriate adjustments consistent with this year's Inventory (e.g., the modified down dead wood estimates). This represents a change in method—that is, including older FIADB data—that does not affect the estimates, because it maintains consistency between successive Inventories.

Estimates for C additions to harvested wood products pools were adjusted due to revision to data for softwood pulpwood production (2006 to 2010), hardwood lumber production (2007 to 2010), hardwood plywood production (2008 to 2010), and imports of particleboard and medium density fiberboard (1998 to 2010). Revisions are contained in Howard (forthcoming). Estimates of the total C stock have been adjusted to represent the stock at the beginning of the year rather than the end of the year to match the beginning year estimates for forest stocks. Previously the estimates had been for the end of the year. This reduced the total stock level estimate for years through 2010 by 20 to 30 Tg C.

Planned Improvements

The ongoing annual surveys by the FIA Program will improve the precision of forest C estimates as new state surveys become available (USDA Forest Service 2012b), particularly in western states. The annual surveys will eventually include all states. To date, three states are not yet reporting any data from the annualized sampling design of FIA: Hawaii, New Mexico and Wyoming. Estimates for these states are currently based on older, periodic data. Hawaii and U.S. territories will also be included when appropriate forest C data are available. In addition, the more intensive sampling of fine woody debris, litter, and SOC on some of the permanent FIA plots continues and will substantially improve resolution of C pools at the plot level for all U.S. forest land as this information becomes available (Woodall et al. 2011b). Improved resolution, incorporating more of Alaska's forests, and using annualized sampling data as it becomes available for those states currently not reporting are planned for future reporting.

As more information becomes available about historical land use, the ongoing effects of changes in land use and forest management will be better accounted for in estimates of soil C (Birdsey and Lewis 2003, Woodbury et al. 2006, Woodbury et al. 2007). Currently, soil C estimates are based on the assumption that soil C density depends only on broad forest type group, not on land-use history, but long-term residual effects on soil and forest floor C stocks are likely after land-use change. Estimates of such effects depend on identifying past land use changes associated with forest lands.

Similarly, agroforestry practices, such as windbreaks or riparian forest buffers along waterways, are not currently accounted for in the inventory. In order to properly account for the C stocks and fluxes associated with agroforestry, research will be needed that provides the basis and tools for including these plantings in a nation-wide inventory, as well as the means for entity-level reporting.

Non-CO_2 Emissions from Forest Fires

Emissions of non-CO_2 gases from forest fires were estimated using the default IPCC (2003) methodology incorporating default IPCC (2006) emissions factors and combustion factor for wildfires. Emissions from this source in 2011 were estimated to be 14.2 Tg CO_2 Eq. of CH_4 and 11.6 Tg CO_2 Eq. of N_2O, as shown in Table 7-12 and Table 7-13. The estimates of non-CO_2 emissions from forest fires account for wildfires in the lower 48 states and Alaska as well as prescribed fires in the lower 48 states.

Table 7-12: Estimated Non-CO_2 Emissions from Forest Fires (Tg CO_2 Eq.) for U.S. Forests[a]

Gas	1990		2005		2007	2008	2009	2010	2011
CH_4	2.5		8.0		14.4	8.7	5.7	4.7	14.2
N_2O	2.0		6.6		11.7	7.1	4.7	3.8	11.6
Total	**4.5**		**14.6**		**26.1**	**15.7**	**10.4**	**8.5**	**25.7**

[a] Calculated based on C emission estimates *in Changes in Forest Carbon Stocks* and default factors in IPCC (2003, 2006).

Table 7-13: Estimated Non-CO_2 Emissions from Forest Fires (Gg Gas) for U.S. Forests[a]

Gas	1990		2005		2007	2008	2009	2010	2011
CH_4	118		383		684	413	271	222	675
N_2O	7		21		38	23	15	12	37

[a] Calculated based on C emission estimates *in Changes in Forest Carbon Stocks* and default factors in IPCC (2003, 2006).

Methodology

The IPCC (2003) Tier 2 default methodology was used to calculate non-CO_2 emissions from forest fires. However, more up-to-date default emission factors from IPCC (2006) were converted into gas-specific emission ratios and incorporated into the methodology. Estimates of CH_4 and N_2O emissions were calculated by multiplying the total estimated CO_2 emitted from forest burned by the gas-specific emissions ratios. CO_2 emissions were estimated by multiplying total C emitted (Table 7-14) by the C to CO_2 conversion factor of 44/12 and by 92.8 percent, which is the estimated proportion of C emitted as CO_2 (Smith 2008a). The equations used were:

$$CH_4 \text{ Emissions} = (\text{C released}) \times 92.8\% \times (44/12) \times (CH_4 \text{ to } CO_2 \text{ emission ratio})$$

$$N_2O \text{ Emissions} = (\text{C released}) \times 92.8\% \times (44/12) \times (N_2O \text{ to } CO_2 \text{ emission ratio})$$

Estimates for C emitted from forest fires are the same estimates used to generate estimates of CO_2 presented earlier in Box 7-1. Estimates for C emitted include emissions from wildfires in both Alaska and the lower 48 states as well as emissions from prescribed fires in the lower 48 states only (based on expert judgment that prescribed fires only occur in the lower 48 states) (Smith 2008a). The IPCC (2006) default combustion factor of 0.45 for "all 'other' temperate forests" was applied in estimating C emitted from both wildfires and prescribed fires. See the explanation in Annex 3.12 for more details on the methodology used to estimate C emitted from forest fires.

Table 7-14: Estimated Carbon Released from Forest Fires for U.S. Forests

Year	C Emitted (Tg/yr)
1990	11.6
2005	37.5
2007	67.1
2008	40.5
2009	26.6
2010	21.8
2011	66.2

Uncertainty and Time-Series Consistency

Non-CO_2 gases emitted from forest fires depend on several variables, including: forest area for Alaska and the lower 48 states; average C densities for wildfires in Alaska, wildfires in the lower 48 states, and prescribed fires in the lower 48 states; emission ratios; and combustion factor values (proportion of biomass consumed by fire). To quantify the uncertainties for emissions from forest fires, a Monte Carlo (Tier 2) uncertainty analysis was performed using information about the uncertainty surrounding each of these variables. The results of the Tier 2 quantitative uncertainty analysis are summarized in Table 7-15.

Table 7-15: Tier 2 Quantitative Uncertainty Estimates of Non-CO_2 Emissions from Forest Fires in Forest Land Remaining Forest Land (Tg CO_2 Eq. and Percent)

Source	Gas	2011 Emission Estimate (Tg CO_2 Eq.)	Uncertainty Range Relative to Emission Estimate (Tg CO_2 Eq.)		(%)	
			Lower Bound	Upper Bound	Lower Bound	Upper Bound
Non-CO_2 Emissions from Forest Fires	CH_4	14.2	2.6	37.6	−82%	+165%
Non-CO_2 Emissions from Forest Fires	N_2O	11.6	2.2	31.0	−81%	+169%

Methodological recalculations were applied to the entire time-series to ensure time-series consistency from 1990 through 2011. Details on the emission trends through time are described in more detail in the Methodology section, above.

QA/QC and Verification

Tier 1 and Tier 2 QA/QC activities were conducted consistent with the U.S. QA/QC plan. Source-specific quality control measures for forest fires included checking input data, documentation, and calculations to ensure data were properly handled through the inventory process. Errors that were found during this process were corrected as necessary.

Recalculations Discussion

For the current Inventory, non-CO_2 emissions were calculated using the 2006 IPCC default emission factors for CH_4 and N_2O instead of the 2003 IPCC default emission factors. These default emission factors were converted to CH_4 to CO_2 and N_2O to CO_2 emission ratios and then multiplied by CO_2 emissions to estimate CH_4 and N_2O emissions. The previous 2003 IPCC methodology provides emission ratios that are multiplied by total C emitted.

The National Association of State Foresters (NASF) releases data on land under wildland protection every several years. In 2011, NASF released these data for the year 2008, which affected the ratio of forest land to land under wildland protection for the years 2007 through 2009. For each of these three years, the updated ratio decreased the forest area burned estimates for the lower forty-eight states by around 15 percent. See the explanation in Annex 3.12 for more details on how the forestland to land under wildland protection ratio is used to calculate forest fire emissions.

In previous Inventory reports, the methodology has assumed that the C density of forest areas burned in wild and prescribed fires does not vary between years. This assumption has been in contrast to the forest C stock estimates, which are updated annually for all years based on data from the USDA Forest Service. The methodology adopted for the current and previous Inventory improves the C density factors by incorporating dynamic C density values based on the annual C pool data provided by the USDA Forest Service for the years 1990 to 2011. As a result of this update, estimates of CO_2 and non-CO_2 emissions from wild and prescribed fires decreased by between 1 and 4 percent as compared to the estimates included in the previous Inventory. This decrease occurred because the dynamic C density values calculated were on average 1% lower (depending on the year) than the C density values previously used for the methodology. For more information on how C density contributes to estimates of emissions from forest fires, see Annex 3.12.

Planned Improvements

The default combustion factor of 0.45 from IPCC (2006) was applied in estimating C emitted from both wildfires and prescribed fires. Additional research into the availability of a combustion factor specific to prescribed fires is being conducted.

Direct N_2O Fluxes from Forest Soils (IPCC Source Category 5A1)

Of the synthetic nitrogen (N) fertilizers applied to soils in the United States, no more than one percent is applied to forest soils. Application rates are similar to those occurring on cropped soils, but in any given year, only a small proportion of total forested land receives N fertilizer. This is because forests are typically fertilized only twice during their approximately 40-year growth cycle (once at planting and once approximately 20 years later). Thus, while the rate of N fertilizer application for the area of forests that receives N fertilizer in any given year is relatively high, the average annual application is quite low as inferred by dividing all forest land that may undergo N fertilization at some point during its growing cycle by the amount of N fertilizer added to these forests in a given year. Direct N_2O emissions from forest soils in 2011 were 0.4 Tg CO_2 Eq. (1 Gg). Emissions have increased by 455 percent from 1990 to 2011as a result of an increase in the area of N fertilized pine plantations in the southeastern United States and Douglas-fir timberland in western Washington and Oregon. Total forest soil N_2O emissions are summarized in Table 7-16.

Table 7-16: Direct N_2O Fluxes from Soils in *Forest Land Remaining Forest Land* (Tg CO_2 Eq. and Gg N_2O)

Year	Tg CO_2 Eq.	Gg
1990	0.1	0.2
2005	0.4	1.2
2007	0.4	1.2
2008	0.4	1.2
2009	0.4	1.2
2010	0.4	1.2
2011	0.4	1.2

Note: These estimates include direct N_2O emissions from N fertilizer additions only. Indirect N_2O emissions from fertilizer additions are reported in the Agriculture chapter. These estimates include emissions from both *Forest Land Remaining Forest Land* and from *Land Converted to Forest Land*.

Methodology

The IPCC Tier 1 approach was used to estimate N_2O from soils within *Forest Land Remaining Forest Land*. According to U.S. Forest Service statistics for 1996 (USDA Forest Service 2001), approximately 75 percent of trees planted were for timber, and about 60 percent of national total harvested forest area is in the southeastern United States. Although southeastern pine plantations represent the majority of fertilized forests in the United States, this Inventory also accounted for N fertilizer application to commercial Douglas-fir stands in western Oregon and Washington. For the Southeast, estimates of direct N_2O emissions from fertilizer applications to forests were based on the area of pine plantations receiving fertilizer in the southeastern United States and estimated application rates (Albaugh et al. 2007; Fox et al. 2007). Not accounting for fertilizer applied to non-pine plantations is justified because fertilization is routine for pine forests but rare for hardwoods (Binkley et al. 1995). For each year, the area of pine receiving N fertilizer was multiplied by the weighted average of the reported range of N fertilization rates (121 lbs. N per acre). Area data for pine plantations receiving fertilizer in the Southeast were not available for 2005, 2006, 2007 and 2008, so data from 2004 were used for these years. For commercial forests in Oregon and Washington, only fertilizer applied to Douglas-fir was accounted for, because the vast majority (~95 percent) of the total fertilizer applied to forests in this region is applied to Douglas-fir (Briggs 2007). Estimates of total Douglas-fir area and the portion of fertilized area were multiplied to obtain annual area estimates of fertilized Douglas-fir stands. The annual area estimates were multiplied by the typical rate used in this region (200 lbs. N per acre) to estimate total N applied (Briggs 2007), and the total N applied to forests was multiplied by the IPCC (2006) default emission factor of 1 percent to estimate direct N_2O emissions. The volatilization and leaching/runoff N fractions for forest land, calculated according to the IPCC default factors of 10 percent and 30 percent, respectively, were included with the indirect emissions in the Agricultural Soil Management source category (consistent with reporting guidance that all indirect emissions are included in the Agricultural Soil Management source category).

Uncertainty and Time-Series Consistency

The amount of N_2O emitted from forests depends not only on N inputs and fertilized area, but also on a large number of variables, including organic C availability, oxygen gas partial pressure, soil moisture content, pH, temperature, and tree planting/harvesting cycles. The effect of the combined interaction of these variables on N_2O flux is complex and highly uncertain. IPCC (2006) does not incorporate any of these variables into the default methodology, except variation in estimated fertilizer application rates and estimated areas of forested land receiving N fertilizer. All forest soils are treated equivalently under this methodology. Furthermore, only synthetic N fertilizers are captured, so applications of organic N fertilizers are not estimated. However, the total quantity of organic N inputs to soils is included in the Agricultural Soil Management and *Settlements Remaining Settlements* sections.

Uncertainties exist in the fertilization rates, annual area of forest lands receiving fertilizer, and the emission factors. Fertilization rates were assigned a default level[228] of uncertainty at ±50 percent, and area receiving fertilizer was assigned a ±20 percent according to expert knowledge (Binkley 2004). IPCC (2006) provided estimates for the uncertainty associated with direct N_2O emission factor for synthetic N fertilizer application to soils. Quantitative uncertainty of this source category was estimated through the IPCC-recommended Tier 2 uncertainty estimation methodology. The uncertainty ranges around the 2005 activity data and emission factor input variables were directly applied to the 2011 emissions estimates. The results of the quantitative uncertainty analysis are summarized in Table 7-17. N_2O fluxes from soils were estimated to be between 0.1 and 1.1 Tg CO_2 Eq. at a 95 percent confidence level. This indicates a range of 59 percent below and 211 percent above the 2011 emission estimate of 0.4 Tg CO_2 Eq.

Table 7-17: Quantitative Uncertainty Estimates of N_2O Fluxes from Soils in *Forest Land Remaining Forest Land* (Tg CO_2 Eq. and Percent)

Source	Gas	2011 Emission Estimate (Tg CO_2 Eq.)	Uncertainty Range Relative to Emission Estimate (Tg CO_2 Eq.)		(%)	
			Lower Bound	Upper Bound	Lower Bound	Upper Bound
Forest Land Remaining Forest Land: N_2O Fluxes from Soils	N_2O	0.4	0.1	1.1	-59%	+211%

Note: This estimate includes direct N_2O emissions from N fertilizer additions to both *Forest Land Remaining Forest Land* and *Land Converted to Forest Land*.

Planned Improvements

State-level area data will be obtained for southeastern pine plantations and northwestern Douglas-fir forests to estimate soil N_2O emission by state and provide information about regional variation in emission patterns.

7.3 Land Converted to Forest Land (IPCC Source Category 5A2)

Land-use change is constantly occurring, and areas under a number of differing land-use types are converted to forest each year, just as forest land is converted to other uses. However, the magnitude of these changes is not currently known. Given the paucity of available land-use information relevant to this particular IPCC source category, it is not possible to separate CO_2 or N_2O fluxes on *Land Converted to Forest Land* from fluxes on *Forest Land Remaining Forest Land* at this time.

[228] Uncertainty is unknown for the fertilization rates so a conservative value of ±50% was used in the analysis.

3.12. Methodology for Estimating N_2O Emissions and Soil Organic C Stock Changes from Agricultural Soil Management (Cropland and Grassland)

Nitrous oxide (N_2O) emissions from agricultural soils result from the interaction of the natural processes of denitrification and nitrification with management practices that add or release mineral nitrogen (N) in the soil profile. Emissions can occur directly in the soil where the N is made available or can be transported to another location following volatilization, leaching, or runoff, and then converted into N_2O. Management also influences soil organic C stocks in agricultural soils by modifying the natural processes of photosynthesis (i.e., crop and forage production) and microbial decomposition. This sub-annex describes the methodologies used to calculate N_2O emissions from agricultural soil management[70] and annual carbon (C) stock changes from mineral and organic soils classified as *Cropland Remaining Cropland*, *Land Converted to Cropland*, *Grassland Remaining Grassland*, and *Land Converted to Grassland*[71]. This annex provides the underlying methodologies for both N_2O emissions from agricultural soil management and soil organic C stock change from mineral and organic soils. There is considerable overlap in the methods and data sets used for these source categories, and the majority of emission are estimated with the same inventory analysis using the DAYCENT simulation model. All Tier 1 and 2 methods are based on the guidelines provided by the IPCC (2006).

A combination of Tier 1, 2 and 3 approaches is used to estimate direct and indirect N_2O emissions, in addition to C stock changes in agricultural soils. More specifically, the methodologies used to estimate soil N_2O emissions include:

1) Tier 3 method to estimate direct emissions from mineral soils for the following crops, including alfalfa hay, barley, corn, cotton, dry beans, grass hay, grass-clover hay, oats, onions, peanuts, potatoes, rice, sorghum, soybeans, sugar beets, sunflowers, tomatoes, and wheat, as well as non-federal grasslands and land use change between cropland (with the crops listed above) and grassland[72], using the DAYCENT process-based simulation model;
2) Tier 1 method to estimate direct N_2O emissions from mineral soils for some vegetables, tobacco, perennial/horticultural crops, and crops that are rotated with these crops, in addition to federal grasslands (i.e., not simulated by DAYCENT);
3) Tier 1 method to estimate direct N_2O emissions due to drainage and cultivation of organic cropland soils;
4) a combination of the Tier 3 and 1 methods to estimate indirect N_2O emissions associated with management of Tier 3 crops (i.e., simulated by DAYCENT; see list above), non-federal grasslands and land use change between cropland and grassland; and
5) Tier 1 method to estimate indirect emissions from some vegetables, tobacco, perennial/horticultural crops, and crops that are rotated with these crops, in addition to federal grasslands and all other land uses.

The methodologies used to estimate soil organic C stock changes include:

1) Tier 3 method to estimate soil organic C stock changes in mineral soils for crops, non-federal grasslands and land use change between grasslands and croplands, using the DAYCENT process-based simulation model;
2) Tier 2 methods with country-specific stock change factors for estimating mineral soil organic C stock changes for crop rotations and land use changes to cropland and grassland (other than the conversions between cropland and grassland) that were not simulated with DAYCENT;
3) Tier 2 methods with country-specific emission factors for estimating losses of C from organic soils that are partly or completely drained for agricultural production; and
4) Tier 2 methods for estimating additional changes in mineral soil C stocks due to sewage sludge additions to soils and enrollment changes in the Conservation Reserve Program (CRP) after 2007.

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[70] Direct Soil N_2O methods from forestlands and settlements are described elsewhere in Forestland Remaining Forestland and Settlements Remaining Settlements.

[71] Soil C stock change methods for forestland are described elsewhere in the Forestland Remaining Forestland section.

[72] The current inventory does not include estimates of direct N_2O emissions for land use change from forestland to grassland or cropland.

As described above, the Inventory uses a Tier 3 approach to estimate direct soil N_2O emissions and C stock changes for the majority of agricultural lands. This approach has several advantages over the IPCC Tier 1 or 2 approaches:

- It utilizes actual weather data at sub-county scales, rather than a broad climate region classification, enabling quantification of inter-annual variability in N_2O emissions and C stock changes at finer spatial scales;
- The model uses a more detailed characterization of spatially-mapped soil properties that influence soil C and N dynamics, as opposed to the broad soil taxonomic classifications of the IPCC methodology;
- The simulation approach provides a more detailed representation of management influences and their interactions than are represented by a discrete factor-based approach in the Tier 1 and 2 methods; and
- Soil N_2O emissions and C stock changes are estimated on a more continuous, daily basis as a function of the interaction of climate, soil, and land management, compared with the linear rate changes that are estimated with the Tier 1 and 2 methods.

The DAYCENT process-based simulation model (daily time-step version of the Century model) has been selected for a Tier 3 approach based on several criteria:

- The model has been developed in the United States and extensively tested and verified for U.S. conditions (e.g., Parton et al. 1987, 1993). In addition, the model has been widely used by researchers and agencies in many other parts of the world for simulating soil C dynamics at local, regional and national scales (e.g., Brazil, Canada, India, Jordan, Kenya, Mexico), and soil N_2O emissions (e.g., Canada, China, Ireland, New Zealand) (Abdalla et al. 2010, Li et al., Smith et al. 2008, Stehfest and Muller 2004) .
- The model is capable of simulating cropland, grassland, forest, and savanna ecosystems, and land-use transitions between these different land uses. It is, thus, well suited to model land-use change effects.
- The model is designed to simulate management practices that influence soil C dynamics and direct N_2O emissions, with the exception of cultivated organic soils; cobbly, gravelly, or shaley soils; and a few crops that have not been parameterized for DAYCENT simulations (e.g., some vegetables, tobacco, perennial/horticultural crops, and crops that are rotated with these crops). For these latter cases, an IPCC Tier 2 method has been used for soil C stock changes and IPCC Tier 1 method for N_2O emissions. The model can also be used estimate the amount of N leaching and runoff, as well as volatilization of N, which is subject to indirect N_2O emissions.
- Much of the data needed for the model is available from existing national databases. The exceptions are CRP enrollment after 2007, management of federal grasslands, and sewage sludge amendments to soils, which are not known at a sufficient resolution to use the Tier 3 model. Soil N_2O emissions and C stock changes associated with these practices are addressed with a Tier 1 and 2 method, respectively.

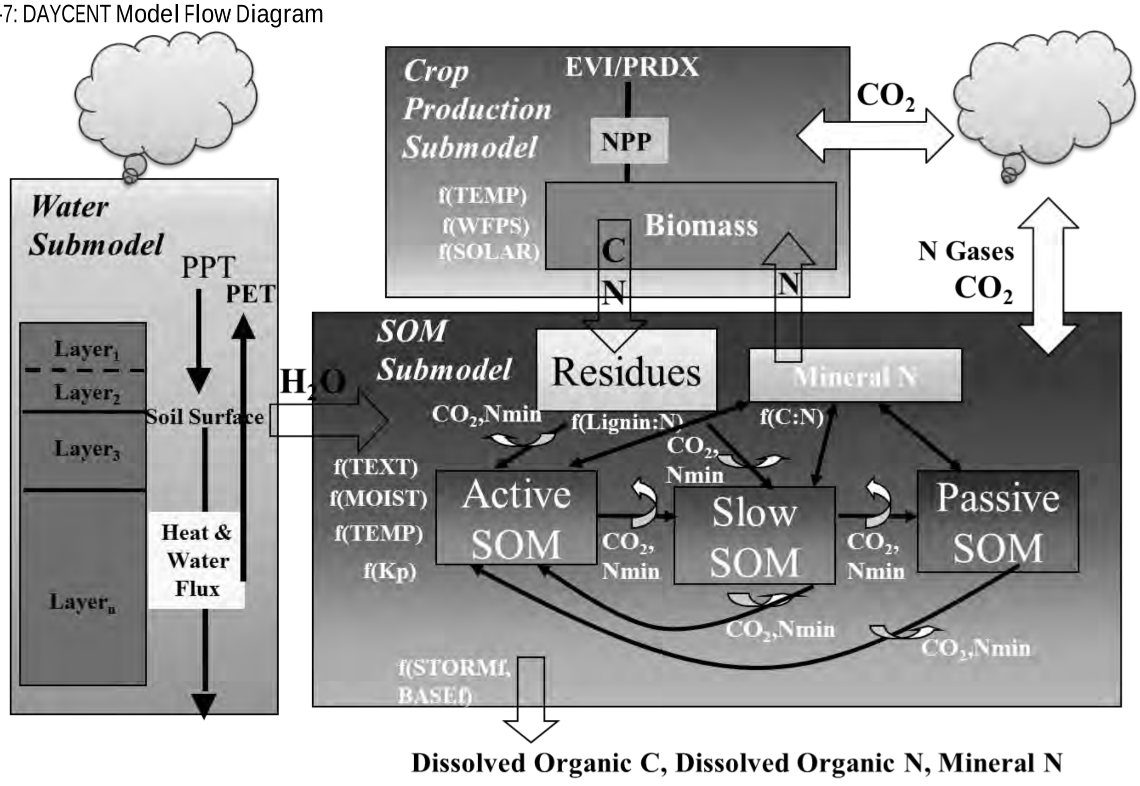
Overall, the Tier 3 approach is used to estimate approximately 79-85 percent of direct soil N_2O emissions and 85-87 percent of the land area associated with estimation of soil organic C stock changes under agricultural management in the United States.

Tier 3 Method Description and Model Evaluation

The DAYCENT process-based model (Parton et al. 1998; Del Grosso et al. 2001, 2011) simulates biogeochemical C and N fluxes between the atmosphere, vegetation, and soil; and provides a more complete estimation of soil C stock changes and N_2O emissions than IPCC Tier 1/2 methods by more thoroughly accounting for the influence of environmental conditions including soil characteristics and weather patterns, specific crop and forage qualities that influence the C and N cycle, and management practices. The DAYCENT model utilizes the soil C modeling framework developed in Century model (Parton et al. 1987, 1988, 1994; Metherell et al. 1993), but has been refined to simulate dynamics at a daily time-step. Carbon and N dynamics are linked in plant-soil systems through biogeochemical processes of microbial decomposition and plant production (McGill and Cole 1981). Coupling the two source categories (i.e., agricultural soil C and N_2O) in a single inventory analysis ensures that there is a consistent treatment of the processes and interactions between C and N cycling in soils. For example, plant growth is controlled by nutrient availability, water, and temperature stress. Plant growth along with the residue management determines the C inputs to soils, which influence the C stock changes, and removal of mineral N from the soil with plant growth influences the amount of N that can be converted into N_2O. Nutrient supply is a function of external nutrient additions as well as litter and soil organic matter (SOM) decomposition rates, and increasing decomposition can lead to a reduction in soil organic C stocks due to microbial respiration, and greater N_2O emissions by enhancing mineral N availability in soils.

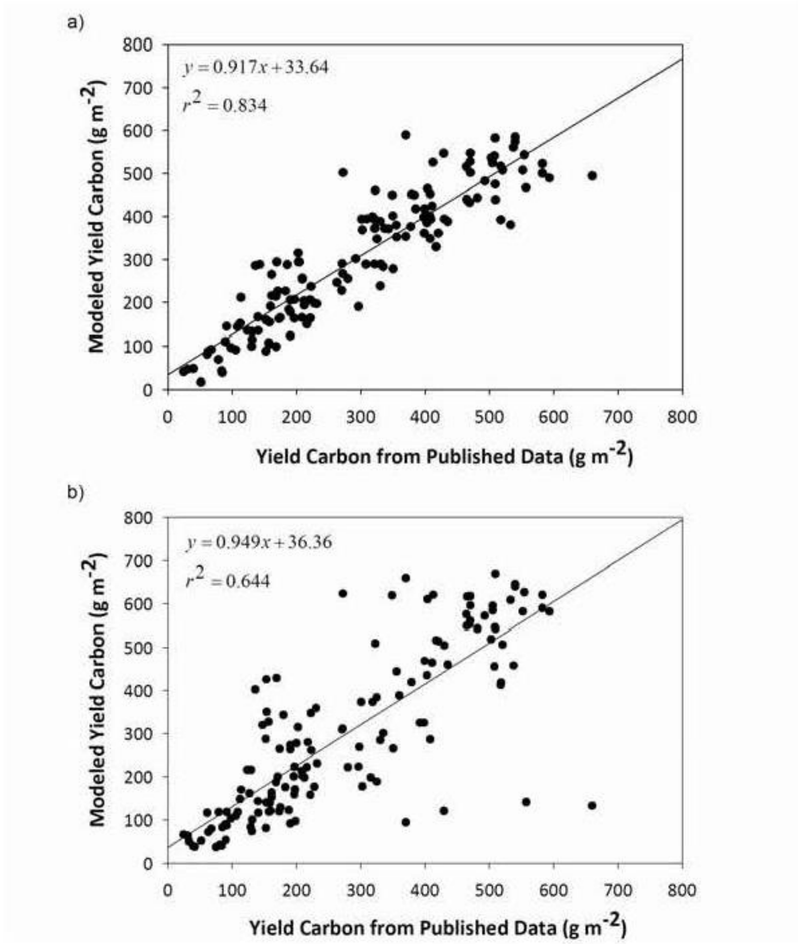
Key processes simulated by DAYCENT include plant production, organic matter formation and decomposition, soil water and temperature regimes by layer, in addition to nitrification and denitrification processes (Figure A-7). The plant-growth submodel simulates C assimilation through photosynthesis; N uptake; dry matter production; partitioning of C within the crop or forage; senescence; and mortality. The primary function of the growth submodel is to estimate the amount, type, and timing of organic matter inputs to soil, and to represent the influence of the plant on soil water, temperature, and N balance. Yield and removal of harvested biomass are also simulated. Separate submodels are designed to simulate herbaceous plants (i.e., agricultural crops and grasses) and woody vegetation (i.e., trees and scrub). Maximum daily net primary production (NPP) is estimated using the NASA-CASA production algorithm (Potter et al.1993, 2007) and MODIS Enhanced Vegetation Index (EVI) products, MOD13Q1 and MYD13Q1, or an approximation of EVI data derived from the MODIS products (Gurung et al. 2009). The NASA-CASA production algorithm is only used for the following major crops: corn, soybeans, sorghum, cotton and wheat.[73] Other crops are simulated with a single value for the maximum daily net primary production (NPP) , instead of the more dynamic NASA-CASA algorithm. The maximum daily NPP rate is modified by air temperature and available water to capture temperature and moisture stress. If the NASA-CASA algorithm is not used in the simulation, then production is further subject to nutrient limitations (i.e., nitrogen). Model evaluation has shown that the NASA-CASA algorithm improves the precision of NPP estimates using the a) NASA-CASA algorithm and b) a single parameter value for maximum net primary production (Spencer et al., in prep;). The r^2 is 83 percent for the NASA-CASA algorithm and 64 percent for the single parameter value approach.).

Figure A-7: DAYCENT Model Flow Diagram



[73] It is a planned improvement to estimate NPP for additional crops and grass forage with the NASA-CASA method in the future.

Figure A-8: Modeled versus measured net primary production (g C m^{-2})



Part a) presents results of the NASA-CASA algorithm (r^2 = 83%) and part b) presents the results of a single parameter value for maximum net primary production (r^2 = 64%).

The soil-water balance submodel calculates water balance components and changes in soil water availability, which influences both plant growth and decomposition/nutrient cycling processes. The moisture content of soils are simulated through a multi-layer profile based on precipitation, snow accumulation and melting, interception, soil and canopy evaporation, transpiration, soil water movement, runoff, and drainage.

Dynamics of soil organic C and N (Figure A-7) are simulated for the surface and subsurface litter pools and the top 20 cm of the soil profile; mineral N dynamics are simulated through the whole soil profile. Organic C and N stocks are represented by two plant litter pools (metabolic and structural) and three soil organic matter (SOM) pools (active, slow, and passive). The metabolic litter pool represents the easily decomposable constituents of plant residues, while the structural litter pool is composed of more recalcitrant, ligno-cellulose plant materials. The three SOM pools represent a gradient in decomposability, from active SOM (representing microbial biomass and associated metabolites) having a rapid turnover (months to years), to passive SOM (representing highly processed, humified, condensed decomposition products), which is highly recalcitrant, with mean residence times on the order of several hundred years. The slow pool represents decomposition products of intermediate stability, having a mean residence time on the order of decades and is the fraction that tends to change the most in response to changes in land use and management. Soil texture influences turnover rates of the slow and passive pools. The clay and silt-sized mineral fraction of the soil provides physical protection from microbial decomposition, leading to enhanced greater SOM stabilization in finely textured soils. Soil temperature and moisture, tillage disturbance, aeration, and other factors influence the decomposition and loss of C from the soil organic matter pools.

Soil mineral N dynamics are modeled based on N inputs from fertilizer inputs (synthetic and organic), residue N inputs, soil organic matter mineralization, symbiotic and asymbiotic N fixation. Mineral N is available for plant and microbial uptake, and is largely controlled by the specified stoichiometric limits for these organisms (i.e., C:N ratios). Mineral and organic N losses are simulated with leaching and runoff, and nitrogen can be volatilized and lost from the soil during a variety of processes including nitrification and denitrification. N_2O emissions from denitrification are a function of soil NO_3^- concentration, water filled pore space (WFPS), heterotrophic (i.e., microbial) respiration, and texture. Nitrification is controlled by soil ammonium (NH_4^+) concentration, water filled pore space, temperature, and pH (See Box 2 for more information).

The final main component of the model is the management submodel, which includes options for specifying crop type, crop sequence (e.g., rotation), tillage, fertilization, organic matter addition (e.g., manure amendments), harvest (with variable residue removal), drainage, irrigation, burning, and grazing intensity. An input "schedule" file is used to simulate the timing of management activities and temporal trends; schedules can be organized into discrete time blocks to define a repeated sequence of events (e.g., a crop rotation or a frequency of disturbance such as a burning cycle for perennial grassland). Management options can be specified for any day of a year within a scheduling block, where management codes point to operation-specific parameter files (referred to as *.100 files), which contain the information used to simulate management effects within the model process algorithms. User-specified management activities can be defined by adding to or editing the contents of the *.100 files. Additional details of the model formulation are given in Parton et al. (1987, 1988, 1994, 1998), Del Grosso et al. (2001, 2011) and Metherell et al. (1993), and archived copies of the model source code are available.

[Begin Text Box]

Box 2. DAYCENT Model Simulation of Nitrification and Denitrification

The DAYCENT model simulates the two biogeochemical processes, nitrification and denitrification, that result in N_2O emissions from soils (Del Grosso et al. 2000, Parton et al. 2001). Nitrification is calculated for the top 15 cm of soil, where nitrification mostly occurs, while denitrification is calculated for the entire soil profile accounting for denitrification near the surface and subsurface as nitrate leaches through the profile. The equations and key parameters controlling N_2O emissions from nitrification and denitrification are described below.

Nitrification is controlled by soil ammonium (NH_4^+) concentration, WFPS, temperature (t), and pH according to the following equation:

$$Nit = NH_4 \times K_{max} \times F(t) \times F(WFPS) \times F(pH)$$

where,

Nit	=	the soil nitrification rate (g N/m^2/day)
NH_4	=	the model-derived soil ammonium concentration (g N/m^2)
K_{max}	=	the maximum fraction of NH_4^+ nitrified (K_{max} = 0.10/day)
F(t)	=	the effect of soil temperature on nitrification (Figure A-9a)
F(WFPS)	=	the effect of soil water content and soil texture on nitrification (Figure A-9b)
F(pH)	=	the effect of soil pH on nitrification (Figure A-9c)

The current parameterization used in the model assumes that 1.2 percent of nitrified N is converted to N_2O.

The model assumes that denitrification rates are controlled by the availability of soil NO_3^- (electron acceptor), labile C compounds (electron donor) and oxygen (competing electron acceptor). Heterotrophic soil respiration is used as a proxy for labile C availability, while oxygen availability is a function of soil physical properties that influence gas diffusivity, soil WFPS, and oxygen demand. The model selects the minimum of the NO_3^- and CO_2 functions to establish a maximum potential denitrification rate. These rates vary for particular levels of electron acceptor and C substrate, and account for limitations of oxygen availability to estimate daily denitrification rates according to the following equation:

$$Den = \min[F(CO_2), F(NO_3)] \times F(WFPS)$$

where,

Den	=	the soil denitrification rate (μg N/g soil/day)
$F(CO_2)$	=	a function relating N gas flux to soil respiration (Figure A-10a)
$F(NO_3)$	=	a function relating N gas flux to nitrate levels (Figure A-10b)
F(WFPS)	=	a dimensionless multiplier (Figure A-10c).

The x inflection point of F(WFPS) is a function of respiration and soil gas diffusivity at field capacity (D_{FC}):

$$x\ inflection = 0.90 - M(CO_2)$$

where,

M= a multiplier that is a function of D_{FC}. In technical terms, the inflection point is the domain where either F(WFPS) not differentiable or its derivative is 0. In this case, the inflection point can be interpreted as the WFPS value at which denitrification reaches half of its maximum rate. In technical terms, the inflection point is the domain where either F(WFPS) not differentiable or its derivative is 0. In this case, the inflection point can be interpreted as the WFPS value at which denitrification reaches half of its maximum rate.

Respiration has a much stronger effect on the water curve in clay soils with low D_{FC} than in loam or sandy soils with high D_{FC} (Figure A-10c). The model assumes that microsites in fine-textured soils can become anaerobic at relatively low water contents when oxygen demand is high.

After calculating total N gas flux, the ratio of N_2/N_2O is estimated so that total N gas emissions can be partitioned between N_2O and N_2:

$$R_{N2/N2O} = F_r(NO_3/CO_2) \times F_r(WFPS).$$

where,

$R_{N2/N2O}$	=	the ratio of N_2/N_2O
$F_r(NO_3/CO_2)$	=	a function estimating the impact of the availability of electron donor relative to substrate
$F_r(WFPS)$	=	a multiplier to account for the effect of soil water on $N_2:N_2O$.

For $F_r(NO_3/CO_2)$, as the ratio of electron donor to substrate increases, a higher portion of N gas is assumed to be in the form of N_2O. For $F_r(WFPS)$, as WFPS increases, a higher portion of N gas is assumed to be in the form of N_2.

[End Box]

Figure A-9: Effect of Soil Temperature, Water-Filled Pore Space, and pH on Nitrification Rates

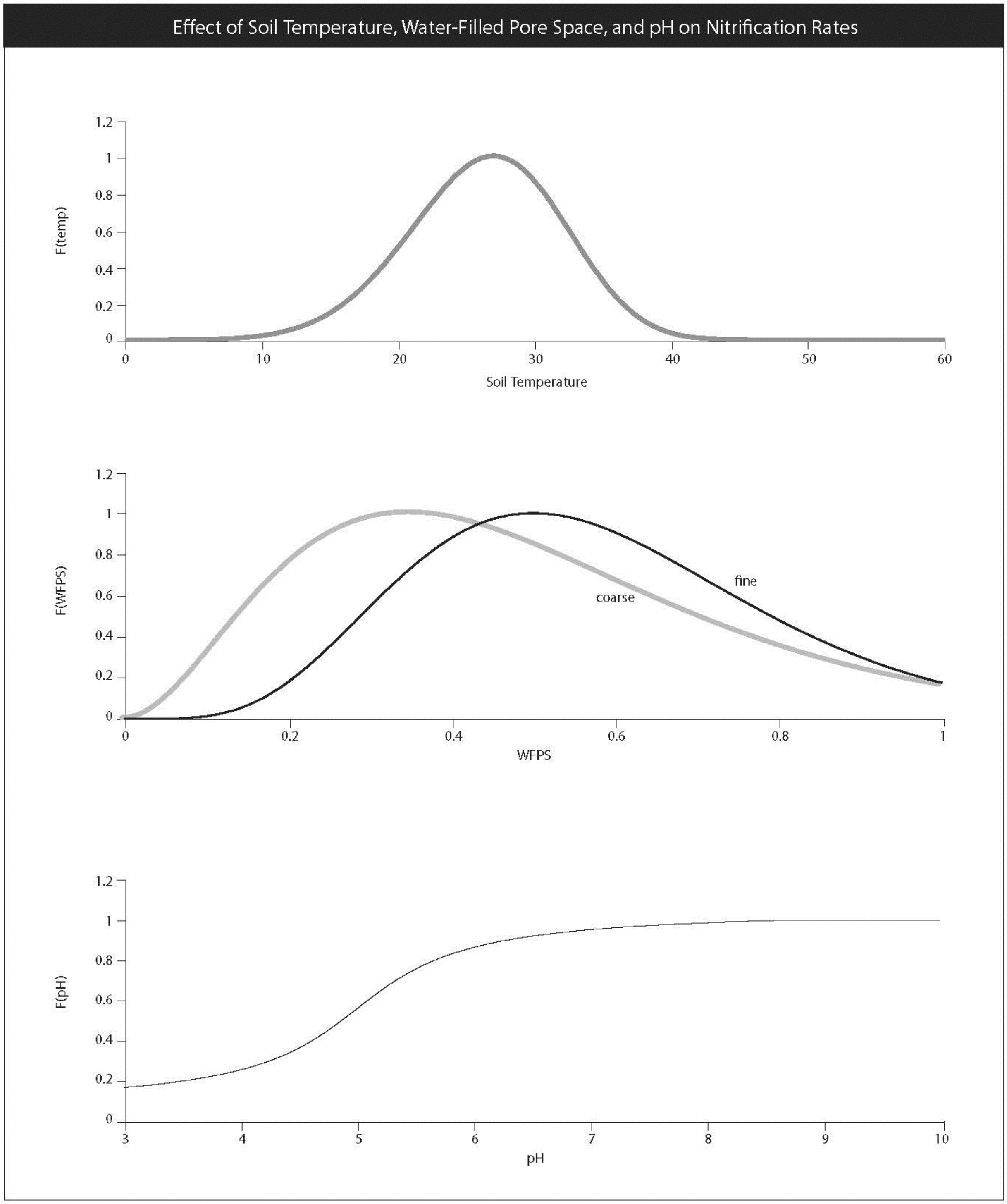
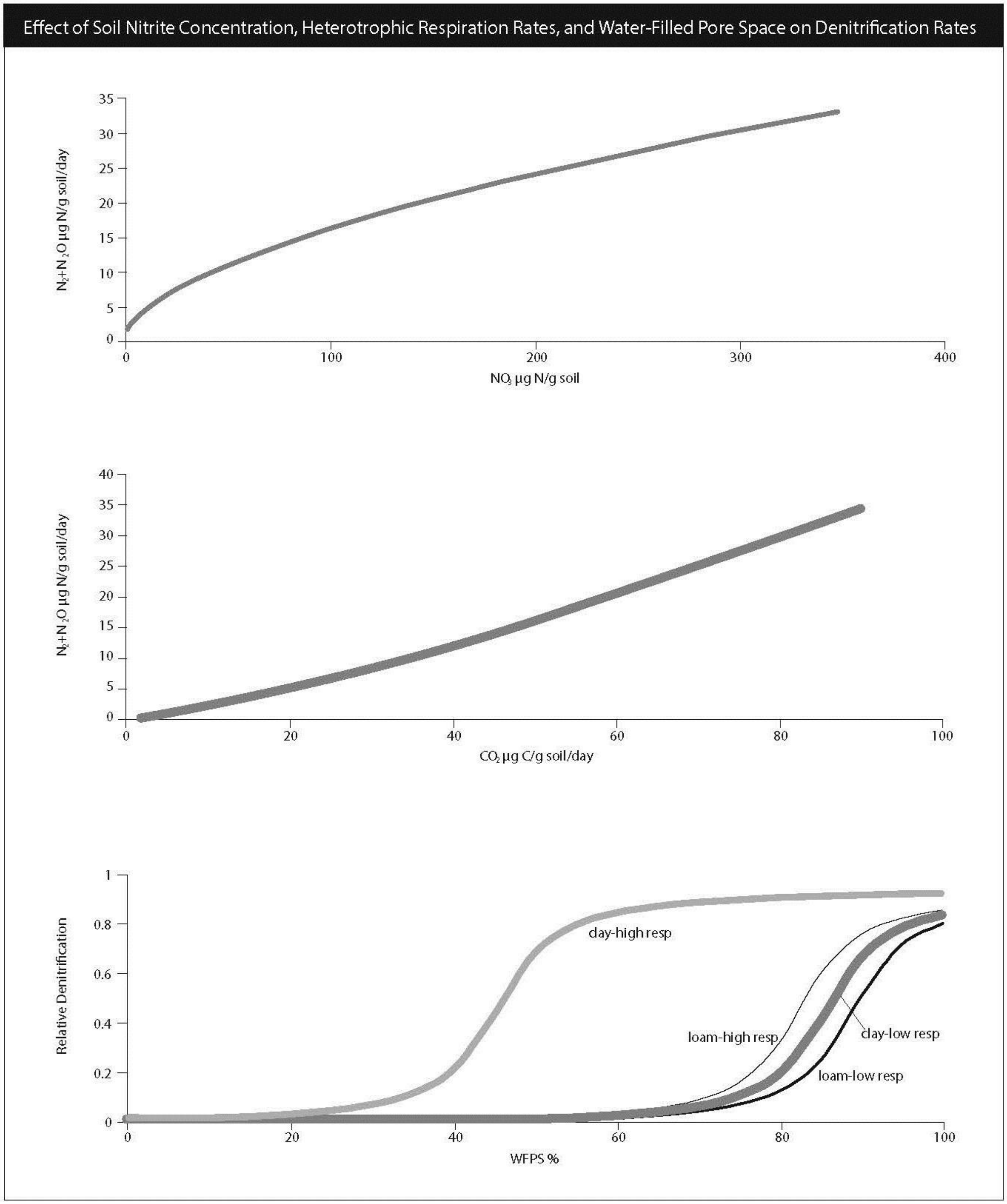


Figure A-10: Effect of Soil Nitrite Concentration, Heterotrophic Respiration Rates, and Water-Filled Pore Space on Denitrification Rates



Comparison of model results and plot level data show that DAYCENT reliably simulates soil organic matter levels (Ogle et al. 2007).The model has been tested for application in U.S. agricultural lands and has been shown to capture the general trends in C storage across approximately 870 field plots from 47 experimental sites (Figure A-11). Some biases and imprecision occur in predictions of soil organic C, which is reflected in the uncertainty associated with DAYCENT model results. Regardless, the Tier 3 approach has considerably less uncertainty than Tier 1 and 2 methods (Del Grosso et al., 201; Figure A-11).

Similarly, DAYCENT model results have been compared to trace gas N_2O fluxes for a number of native and managed systems (Del Grosso et al. 2001, 2005, 2010) (Figure A-12). In general, the model simulates accurate emissions, but some bias and imprecision does occur in predictions, which is reflected in the uncertainty associated with DAYCENT model results. Comparisons with measured data showed that DAYCENT estimated N_2O emissions more accurately and precisely than the IPCC Tier 1 methodology (Figure A-14). The linear regression of simulated vs. measured emissions for DAYCENT had higher r^2 and a fitted line closer to a perfect 1:1 relationship between measured and modeled N_2O emissions (Del Grosso et al. 2005, 2008). This is not surprising, since DAYCENT includes site- specific factors (climate, soil properties, and previous management) that influence N_2O emissions. Furthermore, DAYCENT also simulated NO_3^- leaching (root mean square error = 20 percent) more accurately than IPCC Tier 1 methodology (root mean square error = 69 percent) (Del Grosso et al. 2005). Volatilization of N gases that contribute to indirect soil N_2O emissions is the only component that has not been thoroughly tested, which is due to a lack of measurement data. Thus, the Tier 3 approach has reduced uncertainties in the agricultural soil C stock changes and N_2O emissions compared to using lower Tier methods.

Figure A-11: Comparisons of Results from DAYCENT Model and Measurements of Soil Organic C Stocks

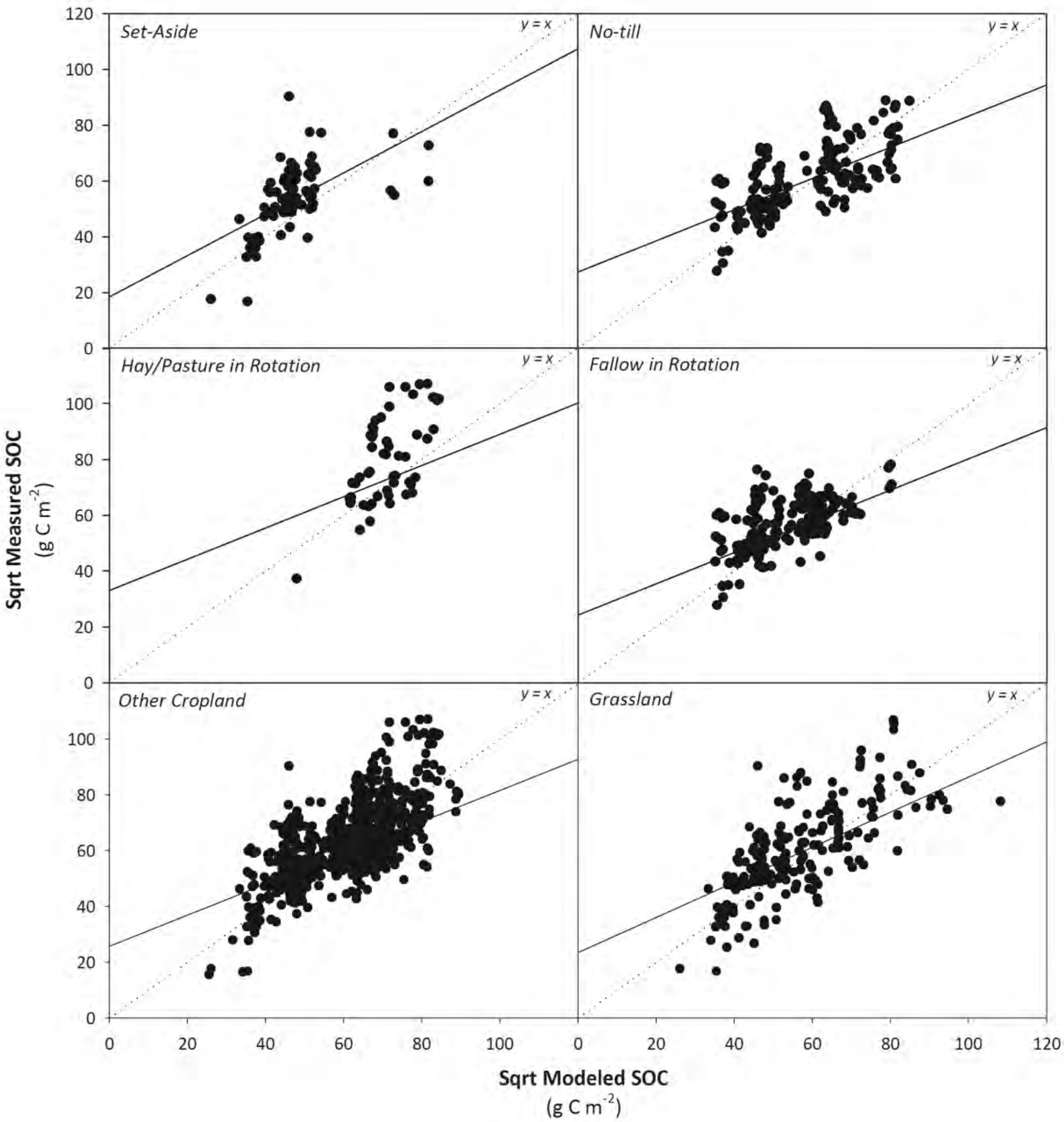
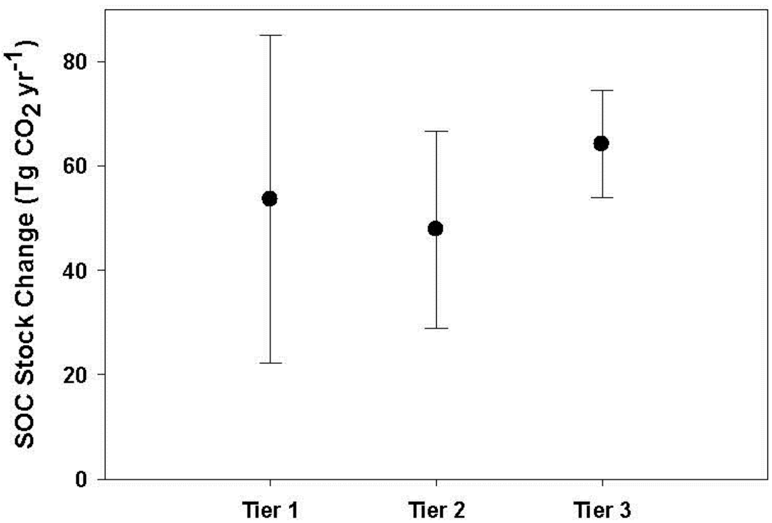


Figure A-12: Comparison of Estimated Soil Organic C Stock Changes and Uncertainties using Tier 1 (IPCC 2006), Tier 2 (Ogle et al. 2003, 2006) and Tier 3 Methods



Source: Tier 1 (IPCC 2007), Tier 2 (Ogle et al. 2003, 2006), Tier 3 (Ogle et al. 2010).

There are five steps in estimating soil organic C stock changes for *Cropland Remaining Cropland*, *Land Converted to Cropland*, *Grassland Remaining Grassland* and *Land Converted to Grassland*; direct N_2O emissions from cropland and grassland soils; and indirect N_2O emissions from volatilization, leaching, and runoff from all managed lands (i.e., croplands, grasslands, forest lands, and settlements). First, the activity data are derived from a combination of land-use, livestock, crop, and grassland management surveys, as well as expert knowledge. In the second, third, and fourth steps, soil organic C stock changes, direct and indirect N_2O emissions are estimated using DAYCENT and/or the Tier 1 and 2 methods. In the fifth step, total emissions are computed by summing all components separately for soil organic C stock changes and N_2O emissions. The remainder of this annex describes the methods underlying each step.

Step 1: Derive Activity Data

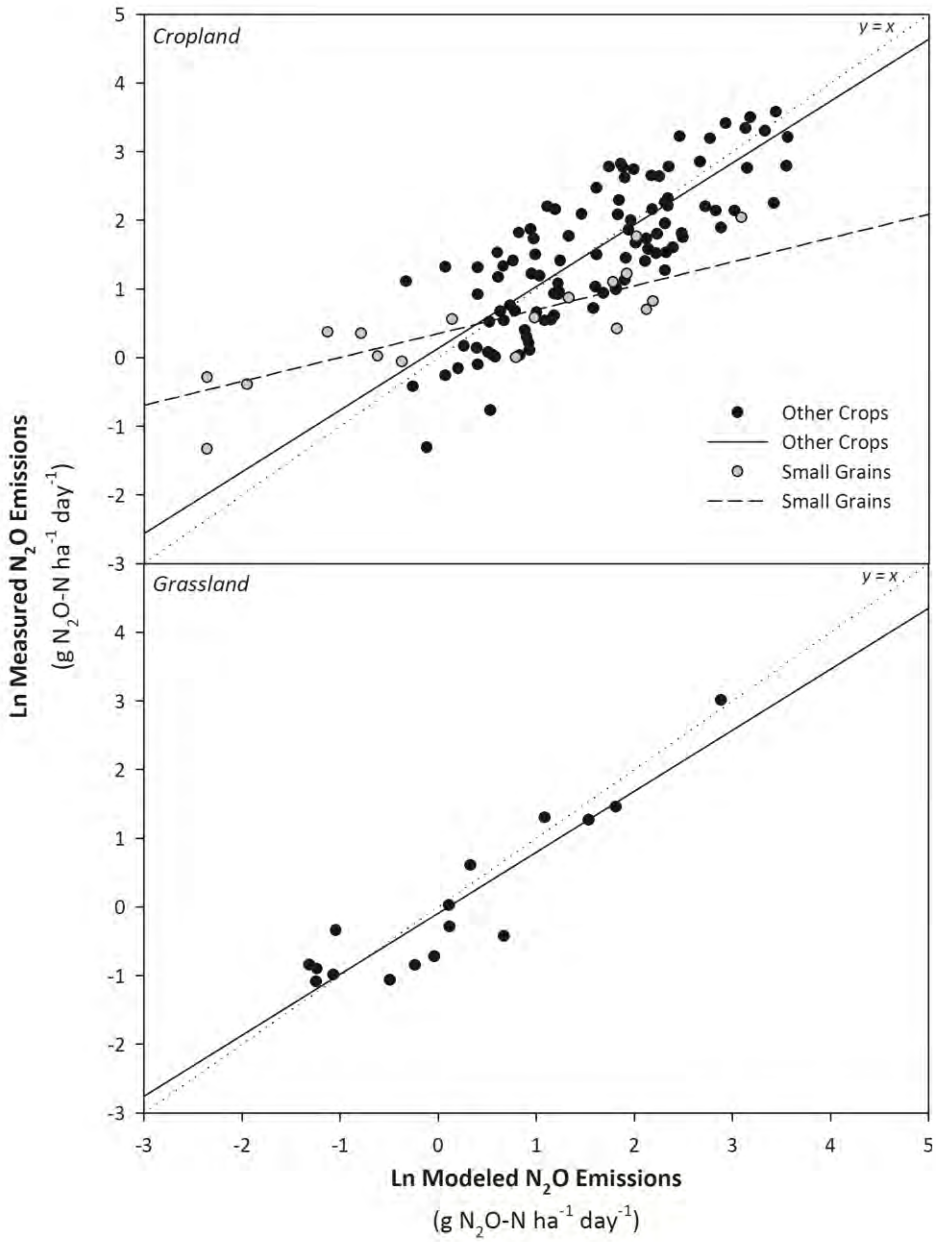
The following describes how the activity data are derived to estimate soil organic C stock changes, in addition to direct and indirect N_2O emissions. The activity data requirements include: (1) land base and history data, (2) crop-specific mineral N fertilizer rates,[74] (3) crop-specific manure amendment N rates and timing, (4) other N inputs, (5) tillage practices, (6) irrigation data, (7) Enhanced Vegetation Index (EVI), (8) daily weather data, and (9) edaphic characteristics.

Step 1a: Activity Data for the Agricultural Land Base and Histories

The U.S. Department of Agriculture's *National Resources Inventory* (NRI) (USDA-NRCS 2009) provides the basis for identifying the U.S. agricultural land base on non-federal lands, and classifying parcels into *Cropland Remaining Cropland*, *Land Converted to Cropland*, *Grassland Remaining Grassland*, and *Land Converted to Grassland*. Note that the Inventory does not include estimates of C stock changes and N_2O emissions for federal grasslands and a minor amount of croplands on federal lands (with the exception of soil N_2O from PRP manure N, i.e., manure deposited by grazing livestock), even though these areas are part of the managed land base for the United States. Greenhouse gas emissions from soils on federal croplands and grasslands will be further evaluated and included in future inventories.

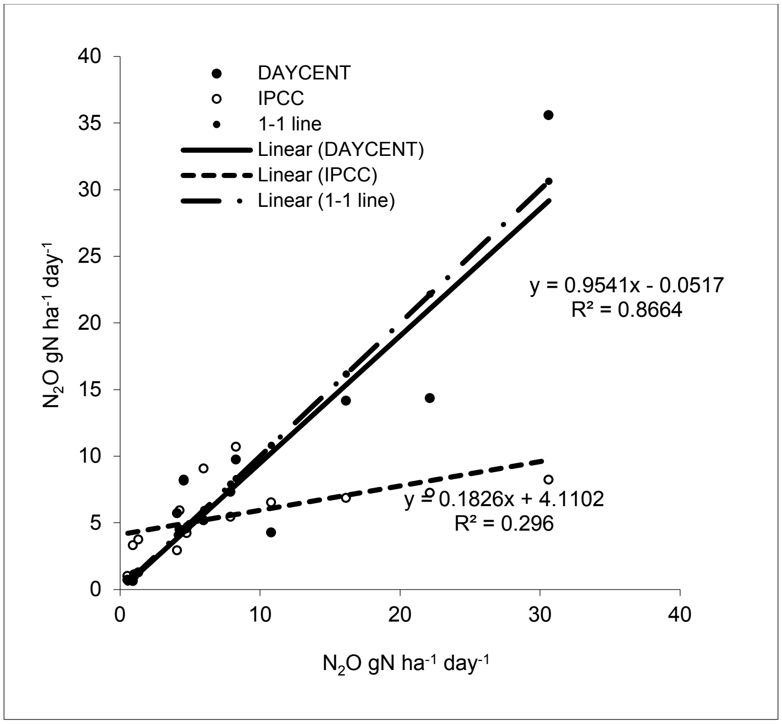
74 No data are currently available at the national scale to distinguish the type of fertilizer applied or timing of applications rates. It is a planned improvement to address variation in these practices in future inventories.

Figure A-13: Comparisons of Results from DAYCENT Model and Measurements of Soil Nitrous Oxide Emissions



The NRI has a stratified multi-stage sampling design, where primary sample units are stratified on the basis of county and township boundaries defined by the U.S. Public Land Survey (Nusser and Goebel 1997). Within a primary sample unit, typically a 160-acre (64.75 ha) square quarter-section, three sample points are selected according to a restricted randomization procedure. Each point in the survey is assigned an area weight (expansion factor) based on other known areas and land-use information (Nusser and Goebel 1997). In principle, the expansion factors represent the amount of area with the land use and land use change history that is the same as the point location. It is important to note that the NRI is a sampling of land use, and therefore there is some uncertainty associated with scaling the point data to a region or the country using the expansion factors. In general, those uncertainties decline at larger scales, such as states compared to smaller county units, because of a larger sample size. An extensive amount of soils, land-use, and land management data have been collected through the survey

Figure A-14: Comparisons of Results from DAYCENT Model and IPCC Tier 1 Method with Measurements of Soil N_2O Emissions



(Nusser et al. 1998).[75] Primary sources for data include aerial photography and remote sensing imagery as well as field visits and county office records.

The annual NRI data product provides crop data for most years between 1979 and 2007, with the exception of 1983, 1988, and 1993. These years are gap-filled using an automated set of rules so that cropping sequences are filled with the most likely crop type given the historical cropping pattern at each NRI point location. Grassland data are reported on 5-year increments prior to 1998, but it is assumed that the land use is also grassland between the years of data collection (see Easter et al. 2008 for more information).

NRI points are included in the land base for the agricultural soil C and N_2O emissions inventories if they are identified as cropland or grassland[76] between 1990 and 2007 (Table A-210).[77] The NRI data are reconciled with the Forest Inventory and Analysis Dataset, and in this process, the time series for *Grassland Remaining Grassland* and *Land Converted to Grassland* is modified to account for differences in forest land area between the two national surveys (See Section 7.1 for more information on the U.S. land representation). Overall, 529,687 NRI survey points are included in the inventory.

For each year, land parcels are subdivided into *Cropland Remaining Cropland*, *Land Converted to Cropland*, *Grassland Remaining Grassland*, and *Land Converted to Grassland*. Land parcels under cropping management in a specific year are classified as *Cropland Remaining Cropland* if the parcel is cropland for at least 20 years. Similarly land parcels under grassland management in a specific year of the inventory are classified as

[75] In the current Inventory, NRI data only provide land-use and management statistics through 2007, but additional data will be incorporated in the future to extend the time series of land use and management data.

[76] Includes non-federal lands only, because federal lands are not classified into land uses as part of the NRI survey (i.e, they are only designated as federal lands).

[77] Land use for 2008 to 2011 is assumed to be the same as 2007, but will be updated after new NRI data are released.

Grassland Remaining Grassland if they are designated as grassland for at least 20 years.[78] Otherwise, land parcels are classified as *Land Converted to Cropland* or *Land Converted to Grassland* based on the most recent use in the inventory time period. Lands are retained in the land-use change categories (i.e., *Land Converted to Cropland* and *Land Converted to Grassland*) for 20 years as recommended by the IPCC guidelines (IPCC 2006).

Table A-210: Total Land Areas for the Agricultural Soil C and N_2O Inventory, Subdivided by Land Use Categories (Million Hectares)

	Land Areas (106 ha)										
Category	**1990**	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**
Mineral Soils											
Cropland Remaining Cropland	152.72	152.52	152.26	147.96	146.80	146.47	146.11	145.72	141.47	141.52	141.54
Land Converted to Cropland	13.84	14.14	14.41	15.55	19.09	19.31	19.65	19.80	19.03	18.58	18.20
Grassland Remaining Grassland	176.07	175.81	175.53	169.51	168.26	168.17	168.10	168.06	165.09	165.18	165.18
Land Converted to Grassland	8.96	9.02	9.15	11.33	11.91	12.16	12.35	12.72	15.08	15.54	16.01
Non-Agricultural Usesa	16.00	16.00	16.00	21.70	21.70	21.70	21.70	21.70	27.59	27.59	27.59
Organic Soils											
Cropland Remaining Cropland	0.63	0.63	0.63	0.61	0.61	0.61	0.61	0.61	0.60	0.60	0.60
Land Converted to Cropland	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07
Grassland Remaining Grassland	0.37	0.37	0.37	0.33	0.33	0.33	0.33	0.33	0.28	0.28	0.28
Land Converted to Grassland	0.16	0.16	0.16	0.20	0.20	0.20	0.20	0.20	0.27	0.27	0.27
Non-Agricultural Usesa	0.16	0.16	0.16	0.20	0.20	0.20	0.20	0.20	0.27	0.27	0.27
Total	**368.88**	**368.77**	**368.64**	**367.32**	**369.04**	**369.09**	**369.18**	**369.27**	**369.56**	**369.71**	**369.83**

Category	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**
Mineral Soils											
Cropland Remaining Cropland	141.54	142.06	144.22	143.27	143.53	143.80	144.42	144.42	144.42	144.42	144.42
Land Converted to Cropland	17.90	17.31	14.62	14.50	14.01	13.54	12.68	12.68	12.68	12.68	12.68
Grassland Remaining Grassland	165.01	165.54	167.89	167.78	167.51	167.47	167.88	167.68	167.47	167.27	167.07
Land Converted to Grassland	16.44	16.02	14.32	15.12	15.12	14.93	14.41	14.34	14.27	14.20	14.14
Non-Agricultural Usesa	27.59	27.59	33.62	33.62	33.62	33.62	33.62	33.62	33.62	33.62	33.62
Organic Soils											
Cropland Remaining Cropland	0.60	0.60	0.62	0.62	0.62	0.62	0.62	0.62	0.62	0.62	0.62
Land Converted to Cropland	0.07	0.07	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
Grassland Remaining Grassland	0.28	0.28	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30
Land Converted to Grassland	0.27	0.27	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33
Non-Agricultural Uses[a]	0.27	0.27	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33
Total	**369.80**	**369.83**	**376.02**	**375.64**	**375.14**	**374.72**	**374.35**	**374.08**	**373.81**	**373.54**	**373.28**

[a] The non-agricultural uses were converted to or from cropland or grassland between 1990 and 2007.

The Tier 3 method using the DAYCENT model is used to estimate soil C stock changes and N_2O emissions for most of the NRI points that occur on mineral soils. Parcels of land that are not simulated with DAYCENT are allocated to the Tier 2 approach for estimating soil organic C stock change, and a Tier 1 method (IPCC 2006) to estimate soil N_2O emissions (Table A- 208) (Note: Tier 1 method for soil N_2O does not require land area data with the exception of emissions from drainage and cultivation of organic soils). The land base that is not simulated with DAYCENT includes (1) land parcels occurring on organic soils; (2) land parcels that include non-agricultural uses such as forest and federal lands in one or more years of the inventory; (3) land parcels on mineral soils that are very gravelly, cobbly, or shaley (i.e., classified as soils that have greater than 35 percent of soil volume comprised of gravel, cobbles, or shale); or (4) land parcels that are used to produce vegetables, perennial/horticultural crops, tobacco or rice, which are either grown continuously or in rotation with other crops. DAYCENT has not been fully tested or developed to simulate biogeochemical processes in soils used to produce some annual (e.g., tobacco),, horticultural (e.g., flowers), or perennial (e.g., vineyards, orchards) crops and agricultural use of organic soils. In addition, DAYCENT has not been adequately tested for soils with a high gravel, cobble, or shale content.

Table A-211: Total Land Area Estimated with Tier 2 and 3 Inventory Approaches (Million Hectares)

	Land Areas (106 ha)

[78] NRI points are classified according to land-use history records starting in 1982 when the NRI survey began, and consequently the classifications are based on less than 20 years from 1990 to 2001.

Year	Tier 2/1	Tier 3	Total
1990	48.58	320.30	368.88
1991	48.58	320.19	368.77
1992	48.58	320.05	368.64
1993	47.41	319.91	367.32
1994	47.41	319.64	367.05
1995	47.41	319.69	367.11
1996	47.41	319.79	367.20
1997	47.41	319.88	367.29
1998	49.92	319.64	369.56
1999	49.92	319.79	369.71
2000	49.92	319.90	369.83
2001	49.92	319.88	369.80
2002	49.92	319.91	369.83
2003	56.13	319.89	376.02
2004	56.13	319.51	375.64
2005	56.13	319.01	375.14
2006	56.13	318.59	374.72
2007	56.13	318.23	374.35
2008	56.13	317.96	374.08
2009	56.13	317.96	374.08
2010	56.13	317.42	373.54
2011	56.13	317.15	373.28

NRI points on mineral soils are classified into specific crop rotations, continuous pasture/rangeland, and other non-agricultural uses for the Tier 2 inventory analysis based on the survey data (Table A-212). NRI points are assigned to IPCC input categories (low, medium, high, and high with organic amendments) according to the classification provided in IPCC (2006). In addition, NRI differentiates between improved and unimproved grassland, where improvements include irrigation and interseeding of legumes. In order to estimate uncertainties, probability distribution functions (PDFs) for the NRI land-use data are constructed as multivariate normal based on the total area estimates for each land-use/management category and associated covariance matrix. Through this approach, dependencies in land use are taken into account resulting from the likelihood that current use is correlated with past use. These dependencies occur because as some land use/management categories increase in area, the area of other land use/management categories will decline. The covariance matrix addresses these relationships.

Table A-212: Total Land Areas by Land-Use and Management System for the Tier 2 Soil Organic C Approach (Million Hectares)

	Land Areas (106 ha)			
Land-Use/Management System	1990-1992 (Tier 2)	1993-1997 (Tier 2)	1998-2002 (Tier 2)	2003-2007 (Tier 2)
Cropland Systems	**17.20**	**15.16**	**15.04**	**13.50**
Aquaculture	0.00	0.00	0.01	0.01
Conservation Reserve Program	0.86	0.80	0.40	0.45
Continuous Hay	1.20	1.16	1.32	1.36
Continuous Hay with Legumes or Irrigation	0.29	0.27	0.31	0.29
Continuous Perennial or Horticultural Crops	0.71	0.59	0.51	0.41
Continuous Rice	0.00	0.00	0.00	0.00
Continuous Row Crops	2.96	2.31	2.55	2.50
Continuous Row Crops and Small Grains	2.01	1.57	1.37	1.29
Continuous Small Grains	0.66	0.57	0.53	0.44
Irrigated Crops	5.61	5.41	5.76	5.04
Low Residue Annual Crops (e.g., Tobacco or Cotton)	0.79	0.90	0.72	0.57
Miscellaneous Crop Rotations	0.00	0.01	0.00	0.00
Rice in Rotation with other crops	0.01	0.00	0.01	0.03
Row Crops and Small Grains in with Hay and/or Pasture	0.47	0.35	0.41	0.22
Row Crops and Small Grains with Fallow	0.05	0.04	0.04	0.04
Row Crops in Rotation with Hay and/or Pasture	0.28	0.30	0.35	0.20
Row Crops with Fallow	0.03	0.01	0.03	0.00
Small Grains in Rotation with Hay and/or Pasture	0.19	0.11	0.10	0.06
Small Grains with Fallow	0.47	0.29	0.18	0.21
Vegetable Crops	0.61	0.47	0.44	0.38
Grassland Systems	**10.63**	**7.51**	**8.53**	**8.72**
Rangeland	3.71	2.88	3.27	3.43
Continuous Pasture	6.84	4.56	5.17	5.16
Continuous Pasture with Legumes or Irrigation	0.08	0.07	0.10	0.13
CRP	0.00	0.00	0.00	0.00
Non-Agricultural Systems	**10.44**	**14.03**	**17.05**	**20.08**
Federal	2.42	2.90	3.05	3.74
Forest	1.52	1.64	1.64	1.64
Water	0.47	0.61	0.76	0.82
Settlements	3.23	5.71	8.11	9.53
Miscellaneous	2.80	3.17	3.49	4.35
Total	**38.27**	**36.70**	**40.63**	**42.30**

For the Tier 3 inventory estimates, the actual cropping and grassland histories are simulated with the DAYCENT model so it is not necessary to classify NRI points into management systems. Uncertainty in the areas associated with each management system is determined from the estimated sampling variance from the NRI survey (Nusser and Goebel 1997). See Step 2b for additional discussion.

Organic soils are also categorized into land-use systems based on drainage (IPCC 2006). Un-drained soils are treated as having no loss of organic C or N_2O emissions. Drained soils are subdivided into those used for cultivated cropland, which are assumed to have high drainage and relatively large losses of C, and those used for managed pasture, which are assumed to have less drainage with smaller losses of C. N_2O emissions are assumed to be similar for both drained croplands and grasslands. Overall, the area of organic soils drained for cropland and grassland has remained relatively stable since 1990 (see Table A-213).

Table A-213: Total Land Areas for Drained Organic Soils By Land Management Category and Climate Region (Million Hectares)

	Land Areas (106 ha)											
	Cold Temperate				Warm Temperate				Tropical			
IPCC Land-Use Category for Organic Soils	1992	1997	2002	2007	1992	1997	2002	2007	1992	1997	2002	2007
Undrained	0.01	0.01	0.01	0.01	0.00	0.00	0.01	0.01	0.06	0.05	0.04	0.01
Managed Pasture (Low Drainage)	0.36	0.34	0.31	0.29	0.03	0.03	0.03	0.02	0.05	0.05	0.03	0.02
Cultivated Cropland (High Drainage)	0.32	0.31	0.33	0.28	0.10	0.10	0.07	0.08	0.20	0.20	0.18	0.18
Other Land Uses[a]	0.07	0.10	0.15	0.17	0.05	0.05	0.06	0.06	0.03	0.05	0.07	0.10
Total	**0.76**	**0.76**	**0.80**	**0.75**	**0.19**	**0.19**	**0.16**	**0.16**	**0.34**	**0.34**	**0.31**	**0.31**

[a]Urban, water, and miscellaneous non-cropland, which are part of the agricultural land base because these areas were converted from or into agricultural land uses between 1990 and 2007.

Step 1b: Obtain Management Activity Data for the Tier 3 Method to estimate Soil C Stock Changes and N_2O Emissions from Mineral Soils

Synthetic N Fertilizer Application: Data on N fertilizer rates are based primarily on the USDA–Economic Research Service Cropping Practices Survey (USDA-ERS 1997, 2011). In these surveys, data on inorganic N fertilization rates are collected for crops simulated by DAYCENT (barley, corn, cotton, dry beans, oats, onions, peanuts, potatoes, rice, sorghum, soybeans, sugar beets, sunflowers, tomatoes, and wheat)in the high production states and for a subset of low production states. These data are used to build a time series of fertilizer application rates for specific crops and regions for the 1990 through 1999 time period and 2000 through 2011 time period. If only a single survey is available for a crop, as is the case with sorghum, the rates for the one survey are used for both time periods.

Mean fertilizer rates and standard deviations for irrigated and rainfed crops are produced for each state. If a state is not surveyed for a particular crop or if there are not enough data to produce a state-level estimate, then data are aggregated to USDA Farm Production Regions in order to estimate a mean and standard deviation for fertilization rates (Farm Production Regions are groups of states in the United States with similar agricultural commodities). If Farm Production Region data are not available, crop data are aggregated to the entire United States (all major states surveyed) to estimate a mean and standard deviation for a particular crop in a state lacking sufficient data. Standard deviations for fertilizer rates are used to construct probability distribution functions (PDFs) with log-normal densities in order to address uncertainties in application rates (see Step 2a for discussion of uncertainty methods). The survey summaries also present estimates for fraction of crop acres receiving fertilizer, and these fractions are used to determine if a crop is receiving fertilizer. Alfalfa hay and grass-clover hay are assumed to not be fertilized, but grass hay is fertilized according to rates from published farm enterprise budgets (NRIAI 2003). Total fertilizer application data are found in Table A- 214.

Simulations are conducted for the period prior to 1990 in order to initialize the DAYCENT model (see Step 2a), and crop-specific regional fertilizer rates prior to 1990 are based largely on extrapolation/interpolation of fertilizer rates from the years with available data. For crops in some agricultural regions, little or no data are available, and, therefore, a geographic regional mean is used to simulate N fertilization rates (e.g., no data are available for the State of Alabama during the 1970s and 1980s for corn fertilization rates; therefore, mean values from the southeastern United States are used to simulate fertilization to corn fields in this state).

Managed Livestock Manure[79]Amendments: County-level manure addition estimates have been derived from manure N addition rates developed by the USDA Natural Resources Conservation Service (NRCS) (Edmonds et al. 2003). Working with the farm-level crop and animal data from the 1997 Census of Agriculture, USDA-NRCS has coupled estimates of manure N produced with estimates of manure N recoverability by animal waste management system to produce county-level rates of manure N application to cropland and pasture. Edmonds et al. (2003) defined a hierarchy that included 24 crops, permanent pasture, and cropland used as pasture. They estimated the area amended with manure and application rates in 1997 for both manure-producing farms and manure-receiving farms within a county and for two scenarios—before implementation of Comprehensive Nutrient Management Plans (baseline) and after implementation (Edmonds et al. 2003). The goal of nutrient management plans is to apply manure nutrients at a rate meeting plant demand, thus limiting leaching losses of nutrients to groundwater and waterways.

For DAYCENT simulations, the rates for manure-producing farms and manure-receiving farms have been area-weighted and combined to produce a single county-level estimate for the amount of land amended with manure and the manure N application rate for each crop in each county. The estimates were based on the assumption that Comprehensive Nutrient Management Plans have not been fully implemented. This is a conservative assumption because it allows for higher leaching rates due to some over-application of manure to soils. Several of the crops in Edmonds et al. (2003) have been area-weighted and combined into broader crop categories. For example, all small grain crops have been combined into one category. In order to address uncertainty in these data, uniform probability distributions are constructed based on the proportion of land receiving manure versus the amount not receiving manure for each crop type and pasture. For example, if 20 percent of land producing corn in a county is amended with manure, randomly drawing a value equal to or greater than 0 and less than 20 would lead to a simulation with a manure amendment, while drawing a value greater than or equal to 20 and less than 100 would lead to no amendment in the simulation (see Step 2a for further discussion of uncertainty methods).

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[79] For purposes of the inventory, total livestock manure is divided into two general categories: (1) managed manure, and (2) unmanaged manure. Managed manure includes manure that is stored in manure management systems such as pits and lagoons, as well as manure applied to soils through daily spread manure operations. Unmanaged manure encompasses all manure deposited on soils by animals on PRP.

Edmonds et al. (2003) only provides manure application rate data for 1997, but the amount of managed manure available for soil application changes annually, so the area amended with manure is adjusted relative to 1997 to account for all the manure available for application in other years. Specifically, the manure N available for application in other years is divided by the manure N available in 1997. If the ratio is greater than 1, there is more manure N available in that county relative to the amount in 1997, and so it is assumed a larger area is amended with manure. In contrast, ratios less than one implied less area is amended with manure because there is a lower amount available in the year compared to 1997. The amendment area in each county for 1997 is multiplied by the ratio to reflect the impact of manure N availability on the area amended. The amount of managed manure N available for application to soils is calculated by determining the populations of animals that are on feedlots or otherwise housed, requiring collection and management of the manure, and the methods are described in the Manure Management section (Section 6.2) and annex (Annex 3.10). The total managed manure N applied to soils is found in Table A- 215.

To estimate C inputs associated with manure N application rates derived from Edmonds et al. (2003), carbon-nitrogen (C:N) ratios for livestock-specific manure types are adapted from the Agricultural Waste Management Field Handbook (USDA 1996), On-Farm Composting Handbook (NRAES 1992), and recoverability factors provided by Edmonds et al (2003). The C:N ratios are applied to county-level estimates of manure N excreted by animal type and management system to produce a weighted county average C:N ratio for manure amendments. The average C:N ratio is used to determine the associated C input for crop amendments derived from Edmonds et al. (2003).

To account for the common practice of reducing inorganic N fertilizer inputs when manure is added to a cropland soil, crop-specific reduction factors are derived from mineral fertilization data for land amended with manure versus land not amended with manure in the ERS 1995 Cropping Practices Survey (ERS 1997). Mineral N fertilization rates are reduced for crops receiving manure N based on a fraction of the amount of manure N applied, depending on the crop and whether it is irrigated or rainfed. The reduction factors are randomly selected from PDFs with normal densities in order to address uncertainties in the dependence between manure amendments and mineral fertilizer application.

PRP Manure N: Another key source of N for grasslands is Pasture/Range/Paddock (PRP) manure N deposition (i.e., manure deposited by grazing livestock). Nitrogen from PRP animal waste deposited on non-federal grasslands was generated internally by the DAYCENT model based on plant biomass and grazing intensity. The simulations assume that on a per unit area basis, more biomass is consumed by grazing animals in more productive pastures than in less productive rangelands. As biomass consumption increases, so does the amount of N deposited by grazing animals. The total PRP manure N added to soils is found in Table A- 215.

Residue N Inputs: Crop residue N, fixation by legumes, and N residue inputs from senesced grass litter are included as sources of N to the soil, and are estimated in the DAYCENT simulations as a function of vegetation type, weather, and soil properties. That is, while the model accounts for the contribution of N from crop residues to the soil profile and subsequent N_2O emissions, this source of mineral soil N is not activity data in the sense that it is not a model input. The simulated total N inputs of above- and below-ground residue N and fixed N that is not harvested and not burned (the DAYCENT simulations assumed that 3 percent of non-harvested above ground residues for grain crops are burned[80]) are provided in Table A-216.

Other N Inputs: Other N inputs are estimated within the DAYCENT simulation, and thus input data are not required, including mineralization from decomposition of soil organic matter and asymbiotic fixation of N from the atmosphere. Mineralization of soil organic matter will also include the effect of land use change on this process as recommended by the IPCC (2006). The influence of additional inputs of N are estimated in the simulations so that there is full accounting of all emissions from managed lands, as recommended by IPCC (2006). The simulated total N inputs from other sources are provided in Table A-216.

Tillage Practices: Tillage practices are estimated for each cropping system based on data from the Conservation Technology Information Center[81] (CTIC 2004). CTIC compiles data on cropland area under five tillage classes by major crop species and year for each county. Because the surveys involve county-level aggregate area, they do not fully characterize tillage practices as they are applied within a management sequence (e.g., crop rotation). This is particularly true for area estimates of cropland under no-till, which include a relatively high proportion of "intermittent"

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[80] Another improvement is to reconcile the amount of crop residues burned with the Field Burning of Agricultural Residues source category (Section 6.5).

[81] National scale tillage data are no longer collected by CTIC, and a new data source will be needed, which is a planned improvement.

no-till, where no-till in one year may be followed by tillage in a subsequent year. For example, a common practice in maize-soybean rotations is to use tillage in the maize crop while no-till is used for soybean, such that no-till practices are not continuous in time. Estimates of the area under continuous no-till are provided by experts at CTIC to account for intermittent tillage activity and its impact on soil C (Towery 2001).

Tillage practices are grouped into 3 categories: full, reduced, and no-tillage. Full tillage is defined as multiple tillage operations every year, including significant soil inversion (e.g., plowing, deep disking) and low surface residue coverage. This definition corresponds to the intensive tillage and "reduced" tillage systems as defined by CTIC (2004). No-till is defined as not disturbing the soil except through the use of fertilizer and seed drills and where no-till is applied to all crops in the rotation. Reduced tillage made up the remainder of the cultivated area, including mulch tillage and ridge tillage as defined by CTIC and intermittent no-till. The specific tillage implements and applications used for different crops, rotations, and regions to represent the three tillage classes are derived from the 1995 Cropping Practices Survey by the Economic Research Service (ERS 1997).

Tillage data are further processed to construct probability distribution functions (PDFs). Transitions between tillage systems are based on observed county-level changes in the frequency distribution of the area under full, reduced, and no-till from the 1980s through 2004. Generally, the fraction of full tillage decreased during this time span, with concomitant increases in reduced till and no-till management. Transitions that are modeled and applied to NRI points occurring within a county are full tillage to reduced and no-till, and reduced tillage to no-till. The remaining amount of cropland is assumed to have no change in tillage (e.g., full tillage remained in full tillage). Transition matrices are constructed from CTIC data to represent tillage changes for three time periods, 1980-1989, 1990-1999, 2000-2011. Areas in each of the three tillage classes—full till (FT), reduced till (RT), no-till (NT)—in 1989 (the first year the CTIC data are available) are used for the first time period, data from 1997 are used for the second time period, and data from 2004 are used for the last time period. Percentage areas of cropland in each county are calculated for each possible transition (e.g., FT→FT, FT→RT, FT→NT, RT→RT, RT→NT) to obtain a probability for each tillage transition at an NRI point. Since continuous NT constituted < 1 percent of total cropland prior to 1990, there are no transitions for NT→FT or NT→NT. Uniform probability distributions are established for each tillage scenario in the county. For example, a particular crop rotation had 80 percent chance of remaining in full tillage over the two decades, a 15 percent chance of a transition from full to reduced tillage and a 5 percent chance of a transition from full to no-till. The uniform distribution is subdivided into three segments with random draws in the Monte Carlo simulation (discussed in Step 2b) leading to full tillage over the entire time period if the value is greater than or equal to 0 and less than 80, a transition from full to reduced till if the random draw is equal to or greater than 80 and less than 95, or a transition from full to no-till if the draw is greater than or equal to 95. See step 2b for additional discussion of the uncertainty analysis.

Irrigation: NRI (USDA-NRCS 2009) differentiates between irrigated and non-irrigated land, but does not provide more detailed information on the type and intensity of irrigation. Hence, irrigation is modeled by assuming that applied water to field capacity with intervals between irrigation events where the soils drain to about 60% of field capacity.

Daily Weather Data: Daily maximum/minimum temperature and precipitation data are based on gridded weather data from the North America Regional Reanalysis Product (NARR) (Mesinger et al. 2006). It is necessary to use computer-generated weather data because weather station data do not exist near all NRI points, and moreover weather station data are for a point in space. The NARR product uses this information with interpolation algorithms to derive weather patterns for areas between these stations. NARR weather data are available for the U.S. from 1980 through 2007 at a 32 km resolution. Each NRI point is assigned the NARR weather data for the grid cell containing the point.

Enhanced Vegetation Index: The Enhanced Vegetation Index (EVI) from the MODIS vegetation products, (MOD13Q1 and MYD13Q1) is an input to DAYCENT for estimating net primary production using the NASA-CASA production algorithm (Potter et al. 1993, 2007). MODIS imagery is collected on a nominal 8 day-time frequency when combining the two products. A best approximation of the daily time series of EVI data is derived using a smoothing process based on the Savitzky-Golay Filter (Savitzky and Golay 1964) after pre-screening for outliers and for cloud-free, high quality data as identified in the MODIS data product quality layer. The NASA-CASA production algorithm is only used for the following major crops: corn, soybeans, sorghum, cotton, wheat and other close-grown crops such as barley and oats[82].

The MODIS EVI products have a 250 m spatial resolution, and some pixels in images have mixed land uses and crop types at this resolution, which is problematic for estimating NPP associated with a specific crop at a NRI point. Therefore, a threshold of 90 percent purity in an individual pixel is the cutoff for estimating NPP using the EVI data derived from the imagery (i.e., pixels with less than 90 percent purity for a crop are assumed to generate bias in the

[82] Additional crops and grassland will be used with the NASA-CASA method in the future, as a planned improvement.

resulting NPP estimates). The USDA-NASS Crop Data Layer (CDL) (Johnson and Mueller 2010) is used to determine the purity levels of the EVI data. CDL data have a 30 to 58 m spatial resolution, depending on the year. The level of purity for individual pixels in the MODIS EVI products is determined by aggregating the crop cover data in CDL to the 250m resolution of the EVI data. In this step, the percent cover of individual crops is determined for the pixels. Pixels that did not meet a 90 percent purity level for any crop are eliminated from the dataset. CDL does not provide full coverage of crop maps for the conterminous United States until 2009 so it is not possible to evaluate purity for the entire cropland area prior to 2009.

The nearest pixel with at least 90 percent purity for a crop is assigned to the NRI point based on a 50 km buffer surrounding the survey location. EVI data are not assigned to a point if there are no pixels with at least 90 percent purity within 50 km buffer. Furthermore, MODIS products do not provide any data on EVI prior to 2000, which preceded the launch of the MODIS sensor on the Aqua and Terra Satellites. It is good practice to apply a method consistently across a time series (IPCC 2006), and so a statistical model is used to estimate EVI for the inventory time series prior to 2000 and also to fill gaps if no pixel has at least 90 percent purity within the 50 km buffer due to purity limitations, lack of CDL data to evaluate purity, or low quality data (Gurung et al. 2009).

Soil Properties: Soil texture and natural drainage capacity (i.e., hydric vs. non-hydric soil characterization) are the main soil variables used as input to the DAYCENT model. Texture is one of the main controls on soil C turnover and stabilization in the DAYCENT model, which uses particle size fractions of sand (50-2,000 µm), silt (2-50 µm), and clay (< 2 µm) as inputs. Hydric condition specifies whether soils are poorly-drained, and hence prone to water-logging, or moderately to well-drained (non-hydric), in their native (pre-cultivation) condition.[83] Poorly drained soils can be subject to anaerobic (lack of oxygen) conditions if water inputs (precipitation and irrigation) exceed water losses from drainage and evapotranspiration. Depending on moisture conditions, hydric soils can range from being fully aerobic to completely anaerobic, varying over the year. Decomposition rates are modified according to a linear function that varies from 0.3 under completely anaerobic conditions to 1.0 under fully aerobic conditions (default parameters in DAYCENT).[84] Other soil characteristics needed in the simulation, such as field capacity and wilting-point water contents, are estimated from soil texture data using a standardized hydraulic properties calculator (Saxton et al. 1986). Soil input data are derived from Soil Survey Geographic Database (SSURGO) (Soil Survey Staff 2011). The data are based on field measurements collected as part of soil survey and mapping. Each NRI point is assigned the dominant soil component in the polygon containing the point from the SSURGO data product.

Step 1c: Obtain Additional Management Activity Data for the Tier 1 Method to estimate Soil N_2O Emissions from Mineral Soils

Synthetic N Fertilizer: A process-of-elimination approach is used to estimate synthetic N fertilizer additions to Tier 1 crops estimates. The total amount of fertilizer used on-farms has been estimated by the USGS from 1990-2001 on a county scale from fertilizer sales data (Ruddy et al. 2006). For 2002 through 2011, county-level fertilizer used on-farms is adjusted based on annual fluctuations in total U.S. fertilizer sales (AAPFCO 1995 through 2011). Fertilizer application data are available for crops and grasslands simulated by DAYCENT (discussed in Step 1a section for Tier 3 crops and non-federal grasslands). Thus, the amount of N applied to Tier 1 crops (i.e., not simulated by DAYCENT) is assumed to be the remainder of the fertilizer used on farms after subtracting the amount applied to Tier 3 crops and non-federal grasslands (i.e., simulated by DAYCENT). The differences are aggregated to the state level, and PDFs are derived based on uncertainties in the amount of N applied to Tier 3 crops and non-federal grasslands. Total fertilizer application to Tier 1 crops is found in Table A- 217.

Managed Livestock Manure and Other Organic Amendments: Manure N that is not applied to crops and grassland simulated by DAYCENT is assumed to be applied to crops not simulated by DAYCENT. Estimates of total national annual N additions from other commercial organic fertilizers are derived from organic fertilizer statistics (TVA 1991 through 1994; AAPFCO 1995 through 2011). AAPFCO fertilizer data are not yet available for 2011, so 2010 values are used as a placeholder until data become available. Commercial organic fertilizers include dried blood, tankage, compost, and other; dried manure and sewage sludge that are used as commercial fertilizer are subtracted from totals to avoid double counting. The dried manure N is counted with the non-commercial manure applications, and sewage sludge is assumed to be applied only to grasslands. The organic fertilizer data, which are recorded in mass units of fertilizer, had

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83 Artificial drainage (e.g., ditch- or tile-drainage) is simulated as a management variable.

84 Hydric soils are primarily subject to anaerobic conditions outside the plant growing season (i.e., in the absence of active plant water uptake). Soils that are water-logged during much of the year are typically classified as organic soils (e.g., peat), which are not simulated with the DAYCENT model.

to be converted to mass units of N by multiplying the consumption values by the average organic fertilizer N contents provided in the annual fertilizer publications. These N contents are weighted average values, and vary from year to year (ranging from 2.3 percent to 3.9 percent over the period 1990 through 2008). The fertilizer consumption data are recorded in "fertilizer year" totals, (i.e., July to June), but are converted to calendar year totals. This is done by assuming that approximately 35 percent of fertilizer usage occurred from July to December and 65 percent from January to June (TVA 1992b). Values for July to December are not available after calendar year 2010 so a "least squares line" statistical extrapolation using the previous 22 years of data is used to arrive at an approximate value. PDFs are derived for the organic fertilizer applications assuming a default ±50 percent uncertainty. Annual consumption of other organic fertilizers is presented in Table A- 218. The fate of manure N is summarized in Table A- 215.

PRP Manure N: Soil N_2O emissions from PRP manure N deposited on federal grasslands is estimated with a Tier 1 method. PRP manure N data are derived using methods described in the Manure Management section (Section 6.2) and Annex 3.10. PRP N deposited on federal grasslands is calculated using a process of elimination approach. The amount of PRP N generated by DAYCENT model simulations of non-federal grasslands was subtracted from total PRP N and this difference was assumed to be applied to federal grasslands. The total PRP manure N added to soils is found in Table A- 215.

Sewage Sludge Amendments: Sewage sludge is generated from the treatment of raw sewage in public or private wastewater treatment works and is typically used as a soil amendment or is sent to waste disposal facilities such as landfills. In this Inventory, all sewage sludge that is amended to agricultural soils is assumed to be applied to grasslands. Estimates of the amounts of sewage sludge N applied to agricultural lands are derived from national data on sewage sludge generation, disposition, and N content. Total sewage sludge generation data for 1988, 1996, and 1998, in dry mass units, are obtained from EPA (1999) and estimates for 2004 are obtained from an independent national biosolids survey (NEBRA 2007). These values are linearly interpolated to estimate values for the intervening years, and linearly extrapolated to estimate values for years since 2004. Sewage sludge generation data are not available after 2004 (Bastian 2007), so the 1990 through 2004 data are linearly extrapolated for the most recent years. The total sludge generation estimates are then converted to units of N by applying an average N content of 3.9 percent (McFarland 2001), and disaggregated into use and disposal practices using historical data in EPA (1993) and NEBRA (2007). The use and disposal practices are agricultural land application, other land application, surface disposal, incineration, landfilling, ocean dumping (ended in 1992), and other disposal. The resulting estimates of sewage sludge N applied to agricultural land are used here; the estimates of sewage sludge N applied to other land and surface-disposed are used in estimating N_2O fluxes from soils in *Settlements Remaining Settlements* (see section 7.5 of the Land Use, Land-Use Change, and Forestry chapter). Sewage sludge disposal data are provided in Table A- 219).

Residue N Inputs: Soil N_2O emissions for residue N inputs from Tier 1 crops (i.e., not simulated by DAYCENT) are estimated with a Tier 1 method. Annual crop yield (metric tons per hectare) and area harvested (hectare) statistics for non-major N-fixing crops, including bean and pulse crops, are taken from U.S. Department of Agriculture crop production reports (USDA 1994, 1998, 2003, 2005, 2006, 2007, 2008, 2009, 2010, 2011, 2012). Crop yield per hectare and area planted are multiplied to determine total crop yield for each crop, which is then converted to tons of dry matter product using the residue dry matter fractions shown in Table A- 220. Dry matter yield is then converted to tons of above- and below-ground biomass N. Above-ground biomass is calculated by using linear equations to estimate above-ground biomass given dry matter crop yields, and below-ground biomass is calculated by multiplying above-ground biomass by the below-to-above-ground biomass ratio. N inputs are estimated by multiplying above- and below-ground biomass by respective N concentrations. All ratios and equations used to calculate residue N inputs are from IPCC (2006) and Williams (2006). PDFs are derived assuming a ±50 percent uncertainty in the yield estimates (NASS does not provide uncertainty), along with uncertainties provided by the IPCC (2006) for dry matter fractions, above-ground residue, ratio of below-ground to above-ground biomass, and residue N fractions. The resulting annual biomass N inputs are presented in Table A- 221.

Step 1d: Obtain Additional Management Activity Data for the Tier 2 Method to estimate Soil C Stock Changes in Mineral Soils

Tillage Practices: For the Tier 2 method used to estimate soil organic C stock changes, PDFs are constructed for the CTIC tillage data (CTIC 2004), as bivariate normal on a log-ratio scale to reflect negative dependence among tillage classes. This structure ensured that simulated tillage percentages are non-negative and summed to 100 percent. CTIC data do not differentiate between continuous and intermittent use of no-tillage, which is important for estimating SOC storage. Thus, regionally based estimates for continuous no-tillage (defined as 5 or more years of continuous use) are modified based on consultation with CTIC experts, as discussed in Step 1a (downward adjustment of total no-tillage acres reported, Towery 2001).

Managed Livestock Manure Amendments: USDA provides information on the amount of land amended with manure for 1997 based on manure production data and field-scale surveys detailing application rates that had been collected in the *Census of Agriculture* (Edmonds et al. 2003). Similar to the DAYCENT model discussion in Step1b, the amount of land receiving manure is based on the estimates provided by Edmonds et al. (2003), as a proportion of crop and grassland amended with manure within individual climate regions. The resulting proportions are used to re-classify a portion of crop and grassland into a new management category. Specifically, a portion of medium input cropping systems is re-classified as high input, and a portion of the high input systems is re-classified as high input with amendment. In grassland systems, the estimated proportions for land amended with manure are used to re-classify a portion of nominally-managed grassland as improved, and a portion of improved grassland as improved with high input. These classification approaches are consistent with the IPCC inventory methodology (IPCC 2006). Uncertainties in the amount of land amended with manure are based on the sample variance at the climate region scale, assuming normal density PDFs (i.e., variance of the climate region estimates, which are derived from county-scale proportions).

Sewage Sludge Amendments: Sewage sludge is generated from the treatment of raw sewage in public or private wastewater treatment works and is typically used as a soil amendment or is sent to waste disposal facilities such as landfills. In this Inventory, all sewage sludge that is amended to agricultural soils is assumed to be applied to grasslands. See section on sewage sludge in Step 1c for more information about the methods used to derive sewage sludge N estimates, and the total amount of sewage sludge N is given in Table A- 219. Sewage sludge N is assumed to be applied at the assimilative capacity provided in Kellogg et al. (2000), which is the amount of nutrients taken up by a crop and removed at harvest, representing the recommended application rate for manure amendments. This capacity varies from year to year, because it is based on specific crop yields during the respective year (Kellogg et al. 2000). Total sewage sludge N available for application is divided by the assimilative capacity to estimate the total land area over which sewage sludge had been applied. The resulting estimates are used for the estimation of soil C stock change.

CRP Enrollment after 2007: The change in enrollment for the Conservation Reserve Program after 2007 is based on the amount of land under active contracts from 2008 through 2011 relative to 2007 (USDA-FSA 2011).

Wetland Reserve: Wetlands enrolled in the Conservation Reserve Program have been restored in the Northern Prairie Pothole Region through the Partners for Wildlife Program funded by the U.S. Fish and Wildlife Service. The area of restored wetlands is estimated from contract agreements (Euliss and Gleason 2002). While the contracts provide reasonable estimates of the amount of land restored in the region, they do not provide the information necessary to estimate uncertainty. Consequently, a ±50 percent range is used to construct the PDFs for the uncertainty analysis.

Table A- 214: Synthetic Fertilizer N Added to Tier 3 Crops (Gg N)

	1990	1995	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Fertilizer N	8,100	8,507	8,579	8,110	8,286	8,505	8,607	8,496	8,421	9,070	8,746	8,508	8,797	8,845

Table A- 215: Fate of Livestock Manure Nitrogen (Gg N)

Activity	1990	1995	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Managed Manure N Applied to Tier 3 Crops and Non-federal Grasslands[a,b]	960	889	1,061	1,020	1,023	1,015	1,018	1,017	981	1,084	1,084	1,084	1,089	1,092
Managed Manure N Applied to Tier 1 Crops[c]	1,539	1,779	1,684	1,711	1,738	1,638	1,682	1,716	1,832	1,748	1,721	1,699	1,700	1,700
Managed Manure N Applied to Grasslands	41	43	44	44	44	43	44	45	45	46	45	44	44	44
Pasture, Range, & Paddock Manure N	4,091	4,556	4,122	4,128	4,115	4,170	4,059	4,135	4,138	4,070	4,017	3,977	3,934	3,845
Total	**6,632**	**7,267**	**6,911**	**6,903**	**6,921**	**6,866**	**6,803**	**6,913**	**6,996**	**6,947**	**6,867**	**6,804**	**6,768**	**6,681**

[a] Accounts for N volatilized and leached/runoff during treatment, storage and transport before soil application.
[b] Includes managed manure and daily spread manure amendments
[c] Totals may not sum exactly due to rounding.

Table A-216: Crop Residue N and Other N Inputs to Tier 3 Crops as Simulated by DAYCENT (Gg N)

Activity	1990	1995	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Residue N[a]	689	735	687	717	649	717	809	710	662	688	688	688	688	688
Mineralization & Asymbiotic Fixation	0,678	1,391	0,659	1,627	1,269	1,178	2,004	0,864	1,414	0,782	0,782	0,782	0,782	0,782

[a] Residue N inputs include unharvested fixed N from legumes as well as crop residue N.

Table A- 217: Synthetic Fertilizer N Added to Tier 1 Crops (Gg N)

Activity	1990	1995	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Fertilizer N	1,261	1,315	1,681	1,385	1,506	1,623	1,826	1,464	1,717	1,552	1,194	1,045	1,230	1,266

Table A- 218: Other Organic Commercial Fertilizer Consumption on Agricultural Lands (Gg N)

Activity	1990	1995	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Other Commercial Organic Fertilizer N[a]	4	10	9	7	8	8	9	10	12	15	12	10	9	10

[a] Includes dried blood, tankage, compost, other. Excludes dried manure and sewage sludge used as commercial fertilizer to avoid double counting.

Table A- 219: Sewage Sludge Nitrogen by Disposal Practice (Gg N)

Disposal Practice	1990	1995	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Applied to Agricultural Soils	52	69	84	86	89	91	94	98	101	104	106	109	112	112
Other Land Application	25	28	30	30	30	30	30	31	31	32	32	32	32	32
Surface Disposal	20	16	10	9	8	6	5	5	4	4	3	3	3	3
Total	**98**	**113**	**124**	**125**	**127**	**128**	**130**	**134**	**136**	**139**	**141**	**144**	**147**	**147**

Note: Totals may not sum due to independent rounding.

Table A- 220: Key Assumptions for Production of Tier 1 Crops and Retention of Crop Residues

Crop	Dry Matter Fraction of Harvested Product	Above-ground Residue Slope	Above-ground Residue Intercept	Ratio of Below-ground Residue to Above-ground Biomass	Residue N Fraction Above-ground	Residue N Fraction Below-ground
Peanuts for Nuts	0.94	1.07	1.54	0.20	0.016	0.014
Dry Edible Beans	0.90	0.36	0.68	0.19	0.010	0.010
Dry Edible Peas	0.91	1.13	0.85	0.19	0.008	0.008
Austrian Winter Peas	0.91	1.13	0.85	0.19	0.008	0.008
Lentils	0.91	1.13	0.85	0.19	0.008	0.008
Wrinkled Seed Peas	0.91	1.13	0.85	0.19	0.008	0.008
Barley	0.89	0.98	0.59	0.22	0.007	0.014
Oats	0.89	0.91	0.89	0.25	0.007	0.008
Rye	0.88	1.09	0.88	0.22	0.005	0.011
Millet	0.90	1.43	0.14	0.22	0.007	0.009
Rice	0.89	0.95	2.46	0.16	0.007	0.009

Table A- 221: Nitrogen in Crop Residues Retained on Soils Producing Tier 1 Crops (Gg N)

Crop	1990	1995	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Peanuts for Nuts	41	41	39	39	38	42	43	39	39	40	30	30	30	30
Dry Edible Beans	11	11	10	9	10	9	9	9	9	9	9	9	9	9
Dry Edible Peas	8	9	9	9	9	9	9	9	8	8	9	10	9	9
Austrian Winter Peas	8	8	8	8	8	8	8	8	8	8	8	8	8	8
Lentils	8	8	9	8	8	8	9	9	8	8	8	9	9	9
Wrinkled Seed Peas	9	9	8	8	8	8	9	8	8	8	8	9	8	8
Barley	20	17	13	11	11	10	10	9	9	9	8	8	8	8
Oats	15	12	11	11	10	11	11	11	11	11	9	9	9	9
Rye	9	8	7	7	7	7	7	7	7	7	7	7	7	7
Millet	6	5	2	3	2	2	2	2	2	2	2	2	2	2
Rice	30	28	31	31	32	31	32	31	31	29	25	25	25	25
Total	**165**	**156**	**146**	**145**	**143**	**147**	**149**	**143**	**141**	**140**	**124**	**125**	**124**	**123**

Step 1e: Additional Activity Data for Indirect N_2O Emissions from Managed Soils of all Land-Use Types

A portion of the N that is applied or deposited as synthetic fertilizer, livestock manure, sewage sludge, and other organic amendments volatilizes as NH_3 and NO_x. In turn, this N is returned to soils through atmospheric deposition, thereby increasing mineral N availability and enhancing N_2O production. Additional N is lost from soils through leaching as water percolates through a soil profile and through runoff with overland water flow. N losses from leaching and runoff enter groundwater and waterways, from which a portion is emitted as N_2O. However, N leaching is assumed to be an insignificant source of indirect N_2O in cropland and grassland systems where the amount of precipitation plus irrigation does not exceed 80 percent of the potential evapotranspiration. These areas are typically semi-arid to arid, and nitrate leaching to groundwater is a relatively uncommon event; moreover IPCC (2006) recommends limiting the amount of nitrate leaching assumed to be a source of indirect N_2O emissions based on precipitation, irrigation and potential evapotranspiration.

The activity data for synthetic fertilizer, livestock manure, other organic amendments, residue N inputs, sewage sludge N, and other N inputs are the same as those used in the calculation of direct emissions from agricultural mineral soils, and may be found in Table A- 214 through Table A- 218, Table A- 221, and Table A- 219. The activity data for computing direct and indirect N_2O emissions from settlements and forest lands are described in the Land Use, Land-Use Change, and Forestry chapter.

Using the DAYCENT model, volatilization and leaching/surface run-off of N from soils is computed internally for Tier 3 cros and non-federal grasslands. DAYCENT simulates the processes leading to these losses of N based on environmental conditions (i.e., weather patterns and soil characteristics), management impacts (e.g., plowing, irrigation, harvest), and soil N availability. Note that the DAYCENT model accounts for losses of N from all anthropogenic activity, not just the inputs of N from mineral fertilization and organic amendments, which are addressed in the Tier 1 methodology. Similarly, the N available for producing indirect emissions resulting from grassland management as well as deposited PRP manure is also estimated by DAYCENT. Estimated leaching losses of N from DAYCENT are not used in the indirect N_2O calculation if the amount of precipitation plus irrigation did not exceed 80 percent of the potential evapotranspiration. Volatilized losses of N are summed for each day in the annual cycle to provide an estimate of the amount of N subject to indirect N_2O emissions. In addition, the daily losses of N through leaching and runoff in overland flow are summed for the annual cycle. Uncertainty in the estimates is derived from uncertainties in the activity data for the N inputs (i.e., fertilizer and organic amendments; see Step 1a for further information).

The Tier 1 method is used to estimate N losses from mineral soils due to volatilization and leaching/runoff for crops, forestland, settlements, sewage sludge applications, and PRP manure on federal grasslands not accounted for by DAYCENT simulations. To estimate volatilized losses, synthetic fertilizers, manure, sewage sludge, and other organic N inputs are multiplied by the fraction subject to gaseous losses using the respective default values of 0.1 kg N/kg N added as mineral fertilizers and 0.2 kg N/kg N added as manure (IPCC 2006). Uncertainty in the volatilized N ranges from 0.03-0.3 kg NH_3-N+NOx-N/kg N for synthetic fertilizer and 0.05-0.5 kg NH_3-N+NOx-N/kg N for organic amendments (IPCC 2006). Leaching/runoff losses of N are estimated by summing the N additions from synthetic and other organic fertilizers, manure, sewage sludge, and above- and below-ground crop residues, and then multiplying by the default fraction subject to leaching/runoff losses of 0.3 kg N/kg N applied, with an uncertainty from 0.1–0.8 kg NO_3-N/kg N (IPCC 2006). However, N leaching is assumed to be an insignificant source of indirect N_2O emissions if the amount of precipitation plus irrigation did not exceed 80 percent of the potential evapotranspiration. PDFs are derived for each of the N inputs in the same manner as direct N_2O emissions, discussed in Steps 1a and 1c.

Volatilized N is summed for losses from Tier 3 crop types, Tier 1 crop types, federal and non-federal grasslands, settlements, and forest lands. Similarly, the annual amounts of N lost from soil profiles through leaching and surface runoff are summed to obtain the total losses for this pathway.

Step 2: Estimate Soil Organic C Stock Changes and Direct N_2O Emissions from Mineral Soils

In this step, soil organic C stock changes and N_2O emissions are estimated for Tier 3 crops, Tier 1 crops, federal and non-federal grasslands. Three methods are used to estimate soil organic C stock changes and direct N_2O emissions from mineral soils. The DAYCENT process-based model is used for Tier 3 crop and non-federal grasslands. A Tier 2 method is used to estimate soil organic C stock changes for crop rotatiosn that weres not simulated by DAYCENT and land use change other than conversions between cropland and grassland. A Tier 1 methodology is used to estimate N_2O emissions from Tier 1 crops, which are grown on a considerably smaller portion of land than the Tier 3 crops, as well as PRP manure N deposition on federal grasslands. Soil organic C stock changes and N_2O emissions are not estimated for federal grasslands (other than the effect of PRP manure N), but are under evaluation as a planned improvement and may be estimated in future inventories.

Step 2a: Estimate Soil Organic C Stock Changes and N_2O Emissions for Crops and Non-Federal Grassland with the Tier 3 DAYCENT Model

Tier 3 crops include alfalfa hay, barley, corn, cotton, dry beans, grass hay, grass-clover hay, oats, onions, peanuts, potatoes, rice, sorghum, soybeans, sugar beets, sunflowers, tomatoes, and wheat, which represent approximately 87 percent of total cropland in the United States. The DAYCENT simulations also included all non-federal grasslands in the United States.

The methodology description is divided into two sub-steps. First, the model is used to establish the initial conditions and C stocks for 1979, which is the last year before the NRI survey is initiated. In the second sub-step, DAYCENT is used to estimate changes in soil organic C stocks and direct N_2O emissions based on the land-use and management histories recorded in the NRI (USDA-NRCS 2009), including the reporting period starting in 1990.

Simulate Initial Conditions (Pre-NRI Conditions): DAYCENT model initialization involves two steps, with the goal of estimating the most accurate stock for the pre-NRI history, and the distribution of organic C among the pools represented in the model (e.g., Structural, Metabolic, Active, Slow, and Passive). Each pool has a different turnover rate (representing the heterogeneous nature of soil organic matter), and the amount of C in each pool at any point in time influences the forward trajectory of the total soil organic C storage. There is currently no national set of soil C measurements that can be used for establishing initial conditions in the model. Sensitivity analysis of the soil organic C algorithms showed that the rate of change of soil organic matter is relatively insensitive to the *amount* of total soil organic C but is highly sensitive to the relative *distribution* of C among different pools (Parton et al. 1987). By simulating the historical land use prior to the inventory period, initial pool distributions are estimated in an unbiased way.

The first step involves running the model to a steady-state condition (e.g., equilibrium) under native vegetation, historical climate data based on the NARR product (1980-2007), and the soil physical attributes for the NRI points. Native vegetation is represented at the MLRA level for pre-settlement time periods in the United States. The model simulates 5,000 years in the pre-settlement era in order to achieve a steady-state condition.

The second step is to simulate the period of time from European settlement and expansion of agriculture to the beginning of the NRI survey, representing the influence of historic land-use change and management, particularly the conversion of native vegetation to agricultural uses. This encompasses a varying time period from land conversion (depending on historical settlement patterns) to 1979. The information on historical cropping practices used for DAYCENT simulations has been gathered from a variety of sources, ranging from the historical accounts of farming practices reported in the literature (e.g., Miner 1998) to national level databases (e.g., NASS 2004). A detailed description of the data sources and assumptions used in constructing the base history scenarios of agricultural practices can be found in Williams and Paustian (2005).

NRI History Simulations: After model initialization, DAYCENT is used to simulate the NRI land use and management histories from 1979 through 2007.[85] The simulations address the influence of soil management on direct N_2O emissions, soil organic C stock changes and losses of N from the profile through leaching/runoff and volatilization. The NRI histories identify the land use and land use change histories for the NRI survey locations, as well as cropping patterns and irrigation history (see Step 1a for description of the NRI data). The input data for the model simulations also include the NARR weather dataset and SSURGO soils data, synthetic N fertilizer rates, managed manure amendments to cropland and grassland, manure deposition on grasslands (i.e., PRP), tillage histories and EVI data (See Step 1b for description of the inputs). The total number of DAYCENT simulations is over 18 million with a 100 repeated simulations (i.e., iterations) for each NRI point location in a Monte Carlo Analysis. The simulation system incorporates a dedicated MySQL database server and a 30-node parallel processing computer cluster. Input/output operations are managed by a set of run executive programs written in PERL.

The simulations for the NRI history are integrated with the uncertainty analysis. Evaluating uncertainty is an integral part of the analysis, and includes three components: (1) uncertainty in the main activity data inputs affecting soil C and N_2O emissions (input uncertainty); (2) uncertainty in the model formulation and parameterization (structural uncertainty); and (3) uncertainty in the land-use and management system areas (scaling uncertainty) (Ogle et al. 2010, Del Grosso et al. 2010). For component 1, input uncertainty is evaluated for fertilization management, manure applications, and tillage, which are primary management activity data that are supplemental to the NRI observations and have significant influence on soil organic C dynamics and N_2O emissions. As described in Step 1b, PDFs are derived from surveys at the county scale for the inputs in most cases. In addition, uncertainty is included for predictions of EVI data that are needed to fill-data gaps and extend the time series (see Enhance Vegetation Index in Step 1b). To represent uncertainty in these inputs, a Monte-Carlo Analysis is used with 100 iterations for each NRI point; random draws are made from PDFs for fertilizer, manure application, tillage, and EVI predictions. As described above, an adjustment factor is also selected from PDFs with normal densities to represent the dependence between manure amendments and N fertilizer application rates.

The second component deals with uncertainty inherent in model formulation and parameterization. This component is generally the largest source of uncertainty in the model-based inventory analysis, accounting for more than 80 percent of the overall uncertainty in the final estimates (Ogle et al. 2010, Del Grosso et al. 2010). An empirically-based

[85] The estimated soil C stock change in 2007 is currently assumed to represent the changes between 2008 and 2011. New estimates will be available in the future to extend the time series of land use and management data.

procedure is applied to develop a structural uncertainty estimator from the relationship between modeled results and field measurements from agricultural experiments (Ogle et al. 2007). For soil organic C, the DAYCENT model is evaluated with measurements from 47 long-term field experiments that have over 800 treatments, representing a variety of management conditions (e.g., variation in crop rotation, tillage, fertilization rates, and manure amendments). There are 12 experimental sites available to evaluate structural uncertainty in the N_2O emission predictions from DAYCENT (Del Grosso et al. 2010). The inputs to the model are essentially known in the simulations for the long-term experiments, and, therefore, the analysis is designed to evaluate uncertainties associated with the model structure (i.e., model algorithms and parameterization).

The relationship between modeled soil organic C stocks and field measurements are statistically analyzed using linear-mixed effect modeling techniques. Additional fixed effects are included in the mixed effect model if they explained significant variation in the relationship between modeled and measured stocks (i.e., if they met an alpha level of 0.05 for significance). Several variables are tested including: land-use class; type of tillage; cropping system; geographic location; climate; soil texture; time since the management change; original land cover (i.e., forest or grassland); grain harvest as predicted by the model compared to the experimental values; and variation in fertilizer and residue management. The final cropland model includes variables for modeled soil organic C inclusion of hay/pasture in cropping rotations, use of no-till, set-aside lands, and inclusion of bare fallow in the rotation, which are significant at an alpha level of 0.05. The final grassland model only included the model soil organic C. These fixed effects are used to make an adjustment to modeled values due to biases that are creating significant mismatches between the modeled and measured stocks. For soil N_2O, simulated DAYCENT emissions are a highly significant predictor of the measurements, with a p-value of <0.01. Several other variables are considered in the statistical model to evaluate if DAYCENT exhibits bias under certain conditions related to climate, soil types, and management practices. The type of crop or grassland is significant at an alpha level of 0.05, demonstrating that DAYCENT tends to over-estimate emissions for small grains systems and grassland, but is accurate in predicting the N_2O emissions for other crops. Random effects are included in the model to capture the dependence in time series and data collected from the same site, which are needed to estimate appropriate standard deviations for parameter coefficients.

A Monte Carlo approach is used to apply the uncertainty estimator (Ogle et al. 2010). Parameter values for the statistical equation (i.e., fixed effects) are selected from their joint probability distribution, as well as random error associated with fine-scale estimates at NRI points, and the residual or unexplained error associated with the linear mixed-effect model. The estimate and associated management information is then used as input into the equation, and adjusted values are computed for each C stock and N_2O emissions estimate. The variance of the adjusted estimates is computed from the 100 simulated values from the Monte Carlo analysis.

The third element is the uncertainty associated with scaling the DAYCENT results for each NRI point to the entire land base, using the expansion factors provided with the NRI survey dataset. The expansion factors represent the number of hectares associated with the land-use and management history for a particular point. This uncertainty is determined by computing the variances of a set of replicated weights for the expansion factor. This uncertainty was included for soil C stock changes and soil nitrous oxide emissions, but was not addressed in the grassland soil N_2O emissions. Further testing is needed to address the uncertainty in grassland soil N_2O, which is a planned improvement for the next inventory.

For the land base that is simulated with the DAYCENT model, soil organic C stock changes are provided in Table A-222, and soil N_2O emissions are provided in Table A-223.

Table A-222: Annual Change in Soil Organic Carbon Stocks (95% Confidence Interval) for the Land Base Simulated with the Tier 3 DAYCENT Model-Based Approach (Tg CO_2 Eq.)

	Cropland Remaining Cropland		Land Converted to Cropland		Grassland Remaining Grassland		Land Converted to Grassland	
Year	Estimate	95% CI	Estimate	95% CI	Estimate	95% CI	Estimate	95% CI
1990	(53.89)	(88.76) to (19.02)	14.06	2.41 to 25.70	(7.87)	(44.77) to 29.03	(4.61)	(9.85) to 0.63
1991	(62.23)	(97.36) to (27.10)	11.33	0.03 to 22.62	(10.66)	(48.11) to 26.79	(5.85)	(11.17) to (0.53)
1992	(54.34)	(85.30) to (23.37)	13.07	1.26 to 24.87	(11.23)	(52.63) to 30.16	(4.77)	(10.37) to 0.83
1993	(54.34)	(87.56) to (21.11)	12.66	0.46 to 24.87	(6.94)	(43.13) to 29.24	(5.81)	(12.12) to 0.50
1994	(59.03)	(88.62) to (29.45)	6.55	(5.27) to 18.36	(20.28)	(58.07) to 17.52	(6.81)	(12.72) to (0.90)
1995	(43.20)	(77.69) to (8.70)	13.69	0.87 to 26.51	(4.49)	(43.43) to 34.45	(6.16)	(12.14) to (0.17)
1996	(49.74)	(76.45) to (23.03)	12.31	(0.67) to 25.29	(19.40)	(57.37) to 18.56	(7.59)	(13.63) to (1.54)
1997	(53.67)	(89.52) to (17.81)	13.72	(0.13) to 27.58	(11.78)	(46.81) to 23.25	(7.01)	(13.18) to (0.84)
1998	(42.08)	(72.65) to (11.51)	8.13	(4.65) to 20.90	(11.87)	(51.23) to 27.49	(7.34)	(13.64) to (1.03)
1999	(44.63)	(73.69) to (15.56)	9.46	(3.33) to 22.25	(4.92)	(40.72) to 30.89	(8.02)	(15.74) to (0.29)

2000	(53.89)	(87.78) to (20.01)	10.21	(4.77) to 25.19	(36.95)	(76.96) to 3.06	(9.38)	(17.01) to (1.76)
2001	(36.24)	(68.95) to (3.53)	10.41	(2.59) to 23.41	(8.58)	(47.69) to 30.53	(8.85)	(16.28) to (1.42)
2002	(26.70)	(62.27) to 8.86	14.12	0.75 to 27.49	(12.94)	(50.17) to 24.29	(8.32)	(16.28) to (0.36)
2003	(24.32)	(60.20) to 11.55	12.19	(0.02) to 24.39	(7.16)	(47.87) to 33.56	(8.17)	(16.71) to 0.37
2004	(30.83)	(66.25) to 4.59	10.74	(0.68) to 22.15	(2.89)	(40.14) to 34.37	(8.41)	(17.29) to 0.48
2005	(44.30)	(73.07) to (15.54)	10.86	(3.36) to 25.07	(2.76)	(46.77) to 41.24	(8.53)	(16.79) to (0.26)
2006	(28.33)	(60.56) to 3.89	11.70	(0.64) to 24.05	(15.33)	(50.76) to 20.09	(9.50)	(17.79) to (1.21)
2007	(30.57)	(62.29) to 1.16	11.82	1.76 to 21.89	5.46	(31.45) to 42.37	(7.32)	(16.57) to 1.94
2008	(30.57)	(62.29) to 1.16	11.82	1.76 to 21.89	5.54	(31.36) to 42.45	(7.25)	(16.47) to 1.96
2009	(30.57)	(62.29) to 1.16	11.82	1.76 to 21.89	5.63	(31.27) to 42.53	(7.19)	(16.36) to 1.98
2010	(30.57)	(62.29) to 1.16	11.82	1.76 to 21.89	5.71	(31.18) to 42.61	(7.13)	(16.26) to 2.00
2011	(30.57)	(62.29) to 1.16	11.82	1.76 to 21.89	5.80	(31.09) to 42.69	(7.06)	(16.16) to 2.03

Table A-223: Annual N_2O Emissions (95% Confidence Interval) for the Land Base Simulated with the Tier 3 DAYCENT Model-Based Approach (Tg CO_2 Eq.)

	Tier 3 Crops		Non-Federal Grasslands	
Year	**Estimate**	**95% CI**	**Estimate**	**95% CI**
1990	86.6	81.39 to 94.08	59.8	56.42 to 64.34
1991	103.3	97.50 to 111.21	57.7	54.37 to 62.14
1992	102.1	96.31 to 110.24	58.0	54.94 to 62.11
1993	108.1	102.15 to 116.18	57.2	54.17 to 61.28
1994	102.0	97.20 to 108.23	61.3	57.23 to 66.97
1995	105.5	100.39 to 112.34	56.5	53.07 to 61.12
1996	113.6	108.02 to 120.99	56.4	53.40 to 60.42
1997	112.0	106.48 to 119.39	62.3	58.64 to 67.17
1998	94.1	89.23 to 100.73	58.0	55.01 to 61.96
1999	99.5	94.69 to 105.75	53.1	50.36 to 56.75
2000	89.4	84.97 to 95.30	56.6	53.62 to 60.48
2001	101.0	95.86 to 108.01	55.8	52.89 to 59.67
2002	97.2	92.09 to 104.27	60.3	56.97 to 64.70
2003	96.1	91.07 to 103.01	61.0	57.45 to 65.71
2004	102.8	97.80 to 109.47	57.4	54.20 to 61.68
2005	105.5	100.25 to 112.58	54.4	51.41 to 58.26
2006	104.9	99.43 to 112.13	55.6	52.45 to 59.75
2007	108.8	102.95 to 116.62	55.7	52.72 to 59.55
2008	106.9	101.04 to 114.71	54.7	51.63 to 58.89
2009	105.5	99.65 to 113.33	55.4	52.21 to 59.72
2010	107.2	101.33 to 115.00	54.1	51.34 to 57.84
2011	107.4	101.60 to 115.27	57.3	54.24 to 61.27

In DAYCENT, the model cannot distinguish among the original sources of N after the N enters the plant and soil system to determine which management activity led to specific N_2O emissions. This means, for example, that N_2O emissions from applied synthetic fertilizer cannot be separated from emissions due to other N inputs, such as crop residues. It is desirable, however, to report emissions associated with specific N inputs. Thus, for each NRI point, the N inputs in a simulation are determined for anthropogenic practices discussed in IPCC (2006), including synthetic mineral N fertilization, organic amendments, and crop residue N added to soils (including N-fixing crops). The percentage of N input for anthropogenic practices is divided by the total N input, and this proportion is used to determine the amount of N_2O emissions assigned to each of the practices.[86] For example, if 70 percent of the mineral N made available in the soil is due to mineral fertilization, then 70 percent of the N_2O emissions are assigned to this practice. The remainder of soil N_2O emissions is reported under "other N inputs," which includes mineralization due to decomposition of soil organic matter and litter, as well as asymbiotic N fixation from the atmosphere. Asymbiotic N fixation by soil bacteria is a minor source of N, typically not exceeding 10 percent of total N inputs to agroecosystems. Mineralization of soil organic matter is a

[86] This method is a simplification of reality to allow partitioning of N_2O emissions, as it assumes that all N inputs have an identical chance of being converted to N_2O. This is unlikely to be the case, but DAYCENT does not track N_2O emissions by source of mineral N so this approximation is the only approach that can be used currently for partitioning N_2O emissions by source of N input. Moreover, this approach is similar to the IPCC Tier 1 method (IPCC 2006), which uses the same direct emissions factor for most N sources (e.g., PRP). Further research and model development may allow for other approaches in the future.

more significant source of N, but is still typically less than half of the amount of N made available in the cropland soils compared to fertilization, manure amendments, and symbiotic fixation. Mineralization of soil organic matter accounts for the majority of available N in grassland soils. Accounting for the influence of "other N inputs" is necessary in order to meet the recommendation of reporting all emissions from managed lands (IPCC 2006). While this method allows for attribution of N_2O emissions to the individual N inputs to the soils, it is important to realize that sources such as synthetic fertilization may have a larger impact on N_2O emissions than would be suggested by the associated level of N input for this source (Delgado et al. 2009). Further research will be needed to improve upon this attribution method, however. The results of subdividing the N_2O emissions based on N inputs are provided in and Table A- 225.

Table A- 224: Direct N_2O Emissions from Cropland Soils (Tg CO_2 Eq.)

Activity	1990	1995	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Mineral Soils	**101.0**	**121.4**	**106.5**	**116.9**	**113.8**	**112.7**	**120.7**	**121.8**	**122.9**	**125.6**	**121.7**	**119.5**	**122.1**	**122.5**
Tier 3 Crops	**86.6**	**105.5**	**89.4**	**101.0**	**97.2**	**96.1**	**102.8**	**105.5**	**104.9**	**108.8**	**106.9**	**105.5**	**107.2**	**107.4**
Synthetic Fertilizer	33.9	41.1	36.3	38.0	37.4	37.5	38.6	41.9	40.2	45.4	43.6	42.4	43.9	44.2
Managed Manure	4.1	4.5	4.4	4.8	4.8	4.5	4.8	5.1	4.9	5.4	5.4	5.4	5.4	5.4
Residue N[a]	2.9	3.6	2.9	3.4	2.9	3.2	3.7	3.6	3.2	3.5	3.5	3.5	3.5	3.5
Mineralization and Asymbiotic Fixation	45.8	56.3	45.8	54.9	52.1	50.9	55.7	55.0	56.5	54.5	54.4	54.3	54.4	54.4
Tier 1 Crops	**14.5**	**15.9**	**17.1**	**15.8**	**16.5**	**16.6**	**17.9**	**16.2**	**18.0**	**16.8**	**14.9**	**14.0**	**14.9**	**15.1**
Synthetic Fertilizer	6.1	6.4	8.2	6.7	7.3	7.9	8.9	7.1	8.4	7.6	5.8	5.1	6.0	6.2
Managed Manure and Other Organic Commercial Fertilizer	7.5	8.7	8.2	8.4	8.5	8.0	8.2	8.4	9.0	8.6	8.4	8.3	8.3	8.3
Residue N	0.8	0.8	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.6	0.6	0.6	0.6
Organic Soils	**2.9**	**2.9**	**2.9**	**2.9**	**2.9**	**2.9**	**2.9**	**2.9**	**2.9**	**2.9**	**2.9**	**2.9**	**2.9**	**2.9**
Total*	**103.9**	**124.3**	**109.4**	**119.8**	**116.7**	**115.6**	**123.6**	**124.7**	**125.8**	**128.5**	**124.6**	**122.4**	**125.0**	**125.4**

+ Less than 0.05 Tg CO_2 Eq.

[a] Residue N inputs include unharvested fixed N from legumes as well as crop residue N.

Table A- 225: Direct N_2O Emissions from Grasslands (Tg CO_2 Eq.)

Activity	1990	1995	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
DAYCENT-Tier 3	**59.8**	**56.5**	**56.6**	**55.8**	**60.3**	**61.0**	**57.4**	**54.4**	**55.6**	**55.7**	**54.7**	**55.4**	**54.1**	**57.3**
Synthetic Fertilizer	3.0	2.4	2.6	2.5	3.1	3.0	2.8	2.9	3.0	2.7	2.4	2.5	2.2	2.1
PRP Manure	9.8	10.2	8.9	9.5	9.8	10.8	9.4	9.4	8.8	9.7	9.5	9.5	9.3	9.8
Managed Manure	0.1	0.1	0.2	0.1	0.2	0.1	0.1	0.1	0.2	0.2	0.1	0.1	0.1	0.1
Residue N[a]	2.7	2.9	2.5	2.7	2.9	2.9	2.7	2.7	2.8	2.7	2.8	2.8	2.7	2.9
Mineralization and Asymbiotic Fixation	44.2	40.8	42.4	41.0	44.4	44.2	42.4	39.2	40.8	40.5	40.0	40.5	39.8	42.3
Tier 1	**18.1**	**19.5**	**19.7**	**18.0**	**19.9**	**17.4**	**16.0**	**16.7**	**20.1**	**14.3**	**13.7**	**13.5**	**13.2**	**12.5**
PRP Manure	17.9	19.1	19.3	17.6	19.5	17.0	15.5	16.2	19.6	13.8	13.2	12.9	12.6	12.0
Sewage Sludge	0.3	0.3	0.4	0.4	0.4	0.4	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.6
Total	**77.9**	**76.0**	**76.3**	**73.8**	**80.2**	**78.4**	**73.4**	**71.1**	**75.7**	**69.9**	**68.4**	**68.9**	**67.3**	**69.8**

[a] Residue N inputs include unharvested fixed N from legumes as well as crop residue N.

Step 2b: Soil N_2O Emissions from Agricultural Lands on Mineral Soils Approximated with the Tier 1 Approach

To estimate direct N_2O emissions from N additions to Tier 1 crops, the amount of N in applied synthetic fertilizer, manure and other commercial organic fertilizers (i.e., dried blood, tankage, compost, and other) is added to N inputs from crop residues, and the resulting annual totals are multiplied by the IPCC default emission factor of 0.01 kg N_2O-N/kg N (IPCC 2006). The uncertainty is determined based on simple error propagation methods (IPCC 2006). The uncertainty in the default emission factor ranges from 0.3–3.0 kg N_2O-N/kg N (IPCC 2006). For flooded rice soils, the IPCC default emission factor is 0.003 kg N_2O-N/kg N and the uncertainty range is 0.000–0.006 kg N_2O-N/kg N (IPCC 2006). Uncertainty in activity data is ± 20 percent for fertilizer additions (Mosier 2004).[87] Uncertainties in the emission factor and fertilizer additions are combined with uncertainty in the equations used to calculate residue N additions from above- and below-ground biomass dry matter and N concentration to derive overall uncertainty.

The Tier 1 method is also used to estimate emissions from manure N deposited by livestock on federal lands (i.e., PRP manure N), and from sewage sludge application to grasslands. These two sources of N inputs to soils are multiplied by the IPCC (2006) default emission factors (0.01 kg N_2O-N/kg N for sludge and horse, sheep, and goat manure, and 0.02 kg N_2O-N/kg N for cattle, swine, and poultry manure) to estimate N_2O emissions. This emission estimate is summed with the DAYCENT simulated emissions to provide the national total for direct N_2O emissions from grasslands (Table A- 225). The uncertainty is determined based on the Tier 1 error propagation methods provided by the IPCC (2006) with uncertainty in the default emission factor ranging from 0.007 to 0.06 kg N_2O-N/kg N (IPCC 2006).

Step 2c: Soil Organic C Stock Changes in Agricultural Lands on Mineral Soils Approximated with the Tier 2 Approach

Mineral soil organic C stock values are derived for crop rotations that were not simulated by DAYCENT and land converted from non-agricultural land uses to cropland or grassland in 1982, 1992, 1997, 2002 and 2007, based on the land-use and management activity data in conjunction with appropriate reference C stocks, land-use change, management, input, and wetland restoration factors. Each input to the inventory calculations for the Tier 2 approach has some level of uncertainty that is quantified in PDFs, including the land-use and management activity data, reference C stocks, and management factors. A Monte Carlo Analysis is used to quantify uncertainty in soil organic C stock changes for the inventory period based on uncertainty in the inputs. Input values are randomly selected from PDFs in an iterative process to estimate SOC change for 50,000 times and produce a 95 percent confidence interval for the inventory results.

Derive Mineral Soil Organic C Stock Change Factors: Stock change factors representative of U.S. conditions are estimated from published studies (Ogle et al. 2003, Ogle et al. 2006). The numerical factors quantify the impact of changing land use and management on SOC storage in mineral soils, including tillage practices, cropping rotation or intensification, and land conversions between cultivated and native conditions (including set-asides in the Conservation Reserve Program). Studies from the United States and Canada are used in this analysis under the assumption that they would best represent management impacts for the Inventory.

The IPCC inventory methodology for agricultural soils divides climate into eight distinct zones based upon average annual temperature, average annual precipitation, and the length of the dry season (IPCC 2006) (Table A-226). Six of these climate zones occur in the conterminous United States and Hawaii (Eve et al. 2001).

Table A-226: Characteristics of the IPCC Climate Zones that Occur in the United States

Climate Zone	Annual Average Temperature (˚C)	Average Annual Precipitation (mm)	Length of Dry Season (months)
Cold Temperate, Dry	< 10	< Potential Evapotranspiration	NA
Cold Temperate, Moist	< 10	≥ Potential Evapotranspiration	NA
Warm Temperate, Dry	10 – 20	< 600	NA
Warm Temperate, Moist	10 – 20	≥ Potential Evapotranspiration	NA
Sub-Tropical, Dry*	> 20	< 1,000	Usually long

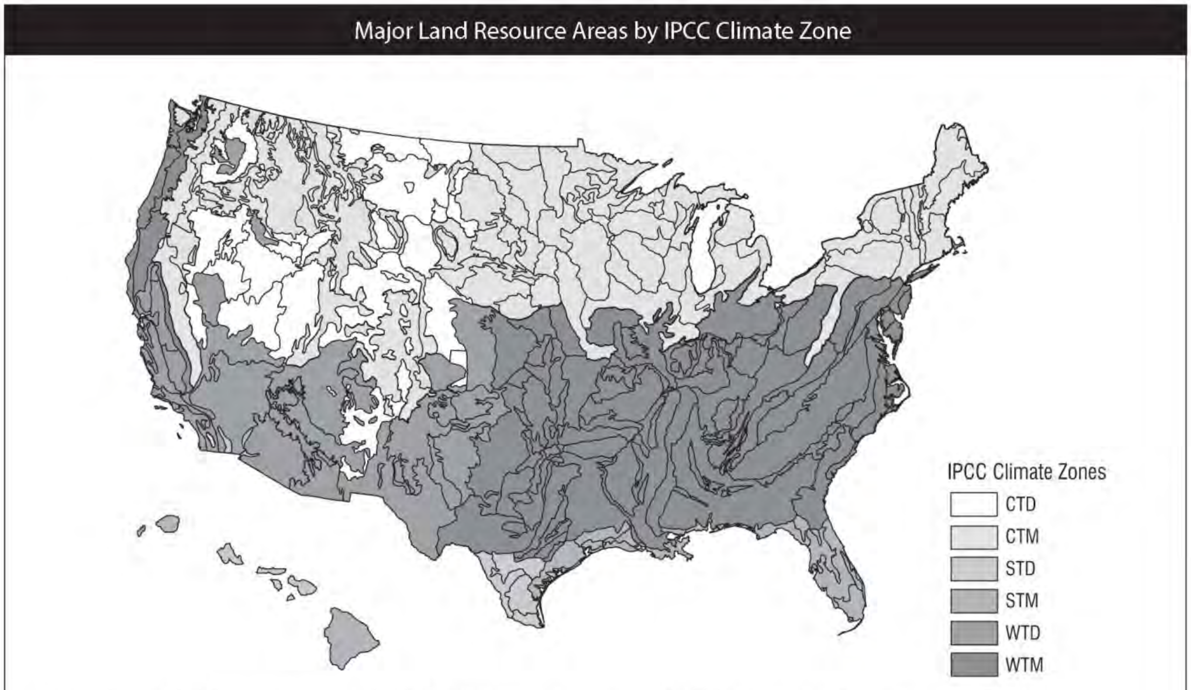
[87] Note that due to lack of data, uncertainties in managed manure N production, PRP manure N production, other commercial organic fertilizer amendments, indirect losses of N in the DAYCENT simulations, and sewage sludge amendments to soils are currently treated as certain; these sources of uncertainty will be included in future Inventories.

Sub-Tropical, Moist (w/short dry season)[a]	> 20	1,000 – 2,000	< 5

[a] The climate characteristics listed in the table for these zones are those that correspond to the tropical dry and tropical moist zones of the IPCC. They have been renamed "sub-tropical" here.

Mean climate (1961-1990) variables from the PRISM data set (Daly et al. 1994) are used to classify climate zones. Mean annual precipitation and annual temperature data are averaged (weighted by area) for each of the 4×4 km grid cells occurring within a MLRA region. These averages are used to assign a climate zone to each MLRA according to the IPCC climate classification (Figure A-15). MLRAs represent geographic units with relatively similar soils, climate, water resources, and land uses; and there are approximately 180 MLRAs in the United States (NRCS 1981).

Figure A-15: Major Land Resource Areas by IPCC Climate Zone



This figure shows the IPCC climate zone assigned to each of the 180 Major Land Resource Areas (MLRAs) in the United States, based on PRISM climate data averaged for each MRLA.

Soils are classified into one of seven classes based upon texture, morphology, and ability to store organic matter (IPCC 2006). Six of the categories are mineral types and one is organic (i.e., Histosol). Reference C stocks, representing estimates from conventionally managed cropland, are computed for each of the mineral soil types across the various climate zones, based on pedon (i.e., soil) data from the National Soil Survey Characterization Database (NRCS 1997) (Table A-227). These stocks are used in conjunction with management factors to compute the change in SOC stocks that result from management and land-use activity. PDFs, which represent the variability in the stock estimates, are constructed as normal densities based on the mean and variance from the pedon data. Pedon locations are clumped in various parts of the country, which reduces the statistical independence of individual pedon estimates. To account for this lack of independence, samples from each climate by soil zone are tested for spatial autocorrelation using the Moran's I test, and variance terms are inflated by 10 percent for all zones with significant p-values.

Table A-227: U.S. Soil Groupings Based on the IPCC Categories and Dominant Taxonomic Soil, and Reference Carbon Stocks (Metric Tons C/ha)

		Reference Carbon Stock in Climate Regions					
IPCC Inventory Soil Categories	USDA Taxonomic Soil Orders	Cold Temperate, Dry	Cold Temperate, Moist	Warm Temperate, Dry	Warm Temperate, Moist	Sub-Tropical, Dry	Sub-Tropical, Moist
High Clay Activity Mineral Soils	Vertisols, Mollisols, Inceptisols, Aridisols, and high base status Alfisols	42 (n = 133)	65 (n = 526)	37 (n = 203)	51 (n = 424)	42 (n = 26)	57 (n = 12)
Low Clay Activity Mineral Soils	Ultisols, Oxisols, acidic Alfisols, and many Entisols	45 (n = 37)	52 (n = 113)	25 (n = 86)	40 (n = 300)	39 (n = 13)	47 (n = 7)
Sandy Soils	Any soils with greater than 70 percent sand and less than 8 percent clay (often Entisols)	24 (n = 5)	40 (n = 43)	16 (n = 19)	30 (n = 102)	33 (n = 186)	50 (n = 18)
Volcanic Soils	Andisols	124 (n = 12)	114 (n = 2)	124 (n = 12)	124 (n = 12)	124 (n = 12)	128 (n = 9)
Spodic Soils	Spodosols	86 (n=20)	74 (n = 13)	86 (n=20)	107 (n = 7)	86 (n=20)	86 (n=20)
Aquic Soils	Soils with Aquic suborder	86 (n = 4)	89 (n = 161)	48 (n = 26)	51 (n = 300)	63 (n = 503)	48 (n = 12)
Organic Soils[a]	Histosols	NA	NA	NA	NA	NA	NA

[a] C stocks are not needed for organic soils.
Notes: C stocks are for the top 30 cm of the soil profile, and are estimated from pedon data available in the National Soil Survey Characterization database (NRCS 1997); sample size provided in parentheses (i.e., 'n' values refer to sample size).

To estimate the land use, management and input factors, studies had to report SOC stocks (or information to compute stocks), depth of sampling, and the number of years since a management change to be included in the analysis. The data are analyzed using linear mixed-effect modeling, accounting for both fixed and random effects. Fixed effects included depth, number of years since a management change, climate, and the type of management change (e.g., reduced tillage vs. no-till). For depth increments, the data are not aggregated for the C stock measurements; each depth increment (e.g., 0-5 cm, 5-10 cm, and 10-30 cm) is included as a separate point in the dataset. Similarly, time series data are not aggregated in these datasets. Linear regression models assume that the underlying data are independent observations, but this is not the case with data from the same experimental site, or plot in a time series. These data are more related to each other than data from other sites (i.e., not independent). Consequently, random effects are needed to account for the dependence in time series data and the dependence among data points representing different depth increments from the same study. Factors are estimated for the effect of management practices at 20 years for the top 30 cm of the soil (Table A-228). Variance is calculated for each of the U.S. factor values, and used to construct PDFs with a normal density. In the IPCC method, specific factor values are given for improved grassland, high input cropland with organic amendments, and for wetland rice, each of which influences C stock changes in soils. Specifically, higher stocks are associated with increased productivity and C inputs (relative to native grassland) on improved grassland with both medium and high input.[88] Organic amendments in annual cropping systems also increase SOC stocks due to greater C inputs, while high SOC stocks in rice cultivation are associated with reduced decomposition due to periodic flooding. There are insufficient field studies to derive factor values for these systems from the published literature, and, thus, estimates from IPCC (2006) are used under the assumption that they would best approximate the impacts, given the lack of sufficient data to derive U.S.-specific factors. A measure of uncertainty is provided for these factors in IPCC (2006), which is used to construct PDFs.

Table A-228: Soil Organic Carbon Stock Change Factors for the United States and the IPCC Default Values Associated with Management Impacts on Mineral Soils

		U.S. Factor			
	IPCC default	Warm Moist Climate	Warm Dry Climate	Cool Moist Climate	Cool Dry Climate
Land-Use Change Factors					
Cultivated[a]	1	1	1	1	1
General Uncult.[a,b] (n=251)	1.4	1.42±0.06	1.37±0.05	1.24±0.06	1.20±0.06
Set-Asidea (n=142)	1.25	1.31±0.06	1.26±0.04	1.14±0.06	1.10±0.05
Improved Grassland Factors[c]					
Medium Input	1.1	1.14±0.06	1.14±0.06	1.14±0.06	1.14±0.06
High Input	Na	1.11±0.04	1.11±0.04	1.11±0.04	1.11±0.04

[88] Improved grasslands are identified in the 2007 *National Resources Inventory* as grasslands that are irrigated or seeded with legumes, in addition to those reclassified as improved with manure amendments.

Wetland Rice Production Factor[b]	1.1	1.1	1.1	1.1	1.1
Tillage Factors					
Conv. Till	1	1	1	1	1
Red. Till (n=93)	1.05	1.08±0.03	1.01±0.03	1.08±0.03	1.01±0.03
No-till (n=212)	1.1	1.13±0.02	1.05±0.03	1.13±0.02	1.05±0.03
Cropland Input Factors					
Low (n=85)	0.9	0.94±0.01	0.94±0.01	0.94±0.01	0.94±0.01
Medium	1	1	1	1	1
High (n=22)	1.1	1.07±0.02	1.07±0.02	1.07±0.02	1.07±0.02
High with amendment[b]	1.2	1.38±0.06	1.34±0.08	1.38±0.06	1.34±0.08

Note: The "n" values refer to sample size.

[a] Factors in the IPCC documentation (IPCC 2006) are converted to represent changes in SOC storage from a cultivated condition rather than a native condition.

[b] U.S.-specific factors are not estimated for land improvements, rice production, or high input with amendment because of few studies addressing the impact of legume mixtures, irrigation, or manure applications for crop and grassland in the United States, or the impact of wetland rice production in the US. Factors provided in IPCC (2006) are used as the best estimates of these impacts.

Wetland restoration management also influences SOC storage in mineral soils, because restoration leads to higher water tables and inundation of the soil for at least part of the year. A stock change factor is estimated assessing the difference in SOC storage between restored and unrestored wetlands enrolled in the Conservation Reserve Program (Euliss and Gleason 2002), which represents an initial increase of C in the restored soils over the first 10 years (Table A-229). A PDF with a normal density is constructed from these data based on results from a linear regression model. Following the initial increase of C, natural erosion and deposition leads to additional accretion of C in these wetlands. The mass accumulation rate of organic C is estimated using annual sedimentation rates (cm/yr) in combination with percent organic C, and soil bulk density (g/cm^3) (Euliss and Gleason 2002). Procedures for calculation of mass accumulation rate are described in Dean and Gorham (1998); the resulting rate and variance are used to construct a PDF with a normal density (Table A-229).

Table A-229: Factor Estimate for the Initial and Subsequent Increase in Organic Soil C Following Wetland Restoration of Conservation Reserve Program

Variable	Value
Factor (Initial Increase—First 10 Years)	1.22±0.18
Mass Accumulation (After Initial 10 Years)	0.79±0.05 Mg C/ha-yr

Note: Mass accumulation rate represents additional gains in C for mineral soils after the first 10 years (Euliss and Gleason 2002).

Estimate Annual Changes in Mineral Soil Organic C Stocks: In accordance with IPCC methodology, annual changes in mineral soil C are calculated by subtracting the beginning stock from the ending stock and then dividing by 20.[89] For this analysis, the base inventory estimate for 1990 through 1992 is the annual average of 1992 stock minus the 1982 stock. The annual average change between 1993 and 1997 is the difference between the 1997 and 1992 C stocks. The annual average change between 1998 and 2002 is the difference between the 1998 and 2002 C stocks. The annual average change between 2003 and 2011 is the difference between the 2003 and 2007. Using the Monte Carlo approach, SOC stock changes for mineral soils are estimated 50,000 times between 1982 and 1992, 1993 and 1997, 1998 and 2002, and 2003 and 2007. From the final distribution of 50,000 values, a 95 percent confidence interval is generated based on the simulated values at the 2.5 and 97.5 percentiles in the distribution (Ogle et al. 2003). Soil organic C stock changes are provided in Table A-230.

Table A-230: Annual Change in Soil Organic Carbon Stocks (95% Confidence Interval) for the Land Base Estimated with the Tier 2 Analysis using U.S. Factor Values and Reference Carbon Stocks (Tg CO_2 Eq./yr)

	Cropland Remaining Cropland		Land Converted to Cropland		Grassland Remaining Grassland*		Land Converted to Grassland*	
Year	Estimate	95% CI	Estimate	95% CI	Estimate	95% CI	Estimate	95% CI
Mineral Soils								
1990-1992	(6.49)	(4.1) to (9.2)	4.81	2.7 to 7.2	(0.19)	(0.03) to (0.4)	(3.50)	(2.2) to (5.0)
1993-1997	(7.64)	(4.8) to (10.7)	4.69	2.5 to 7.1	(0.08)	(<0.01) to 0.18	(3.56)	(2.2) to (5.1)
1998-2002	(6.93)	(4.4) to (9.7)	3.72	1.9 to 5.7	(0.01)	(0.08) to 0.06	(3.60)	(2.2) to (5.2)
2003-2011	(2.83)	(0.9) to (5.1)	1.55	0.8 to 2.4	0.10	0.01 to 0.21	(2.50)	(1.4) to (3.7)
Organic Soils								
1990-1992	26.29	17.4 to 38.2	2.16	1.3 to 3.3	3.39	1.8 to 5.6	0.43	0.2 to 0.8

89 The difference in C stocks is divided by 20 because the stock change factors represent change over a 20-year time period.

1993-1997	25.67	16.9 to 37.5	2.51	1.5 to 3.8	3.01	1.6 to 5.0	0.73	0.4 to 1.3
1998-2002	25.66	16.9 to 37.5	2.54	1.4 to 4.0	2.61	1.4 to 4.3	0.86	0.4 to 1.5
2003-2011	26.80	17.7 to 39.0	1.13	0.3 to 2.2	2.78	1.5 to 4.6	0.79	0.4 to 1.4

Step 2d: Estimate Additional Changes in Soil Organic C Stocks Due to CRP Enrollment after 2007 and Sewage Sludge Amendments

There are two additional land use and management activities in U.S. agricultural lands that are not estimated in Steps 2a and 2b. The first activity involves the application of sewage sludge to agricultural lands. Minimal data exist on where and how much sewage sludge is applied to U.S. agricultural soils, but national estimates of mineral soil land area receiving sewage sludge can be approximated based on sewage sludge N production data, and the assumption that amendments are applied at a rate equivalent to the assimilative capacity from Kellogg et al. (2000). It is assumed that sewage sludge for agricultural land application is applied to grassland because of the high heavy metal content and other pollutants found in human waste, which limits its application to crops. The impact of organic amendments on SOC is calculated as 0.38 metric tonnes C/ha-yr. This rate is based on the IPCC default method and country-specific factors (see Table A-232), by calculating the effect of converting nominal, medium-input grassland to high input improved grassland. The assumptions are that reference C stock are 50 metric tonnes C/ha, which represents a mid-range value of reference C stocks for the cropland soils in the United States[90], that the land use factor for grassland of 1.4 and 1.11 for high input improved grassland are representative of typical conditions, and that the change in stocks are occurring over a 20 year (default value) time period (i.e., [50 × 1.4 × 1.11 – 50 × 1.4] / 20 = 0.38). A nominal ±50 percent uncertainty is attached to these estimates due to limited information on application and the rate of change in soil C stock change with sewage sludge amendments. The influence of sewage sludge on soil organic C stocks are available in Table A-232.

The second activity is the change in enrollment for the Conservation Reserve Program after 2007 for mineral soils. Relative to the enrollment in 2007, the total area in the Conservation Reserve Program has decreased from 2008 to 2011 (USDA-FSA 2011). An average annual change in SOC of 0.5 metric tonnes C/ha-yr is used to estimate the effect of the enrollment changes. This rate is based on the IPCC default method and country-specific factors (see Table A-228) by estimating the impact of setting aside a medium input cropping system in the Conservation Reserve Program. The assumptions are that reference C stock are 50 metric tonnes C/ha, which represents a mid-range value for the dominant cropland soils in the United States, and the average country-specific factor is 1.2 for setting-aside cropland from production, with the change in stocks occurring over a 20 year (default value) time period equal to 0.5 (i.e., [50 × 1.2 – 50] / 20 = 0.5). A nominal ±50 percent uncertainty is attached to these estimates due to limited information about the enrollment trends at subregional scales, which creates uncertainty in the rate of soil C stock change (stock change factors for set-aside lands vary by climate region). Estimates and uncertainties are available in Table A-236.

Step 3: Estimate Soil Organic C Stock Changes and Direct N_2O Emissions from Organic Soils

In this step, soil organic C losses and N_2O emissions are estimated for organic soils that are drained for agricultural production.

Step 3a: Direct N_2O Emissions Due to Drainage and Cultivation of Organic Cropland Soils

To estimate annual N_2O emissions from drainage and cultivation of organic soils, the area of cultivated organic soils in temperate regions is multiplied by the IPCC (2006) default emission factor for temperate soils and the corresponding area in sub-tropical regions is multiplied by the average (12 kg N_2O-N/ha cultivated) of IPCC (2006) default emission factors for temperate (8 kg N_2O-N/ha cultivated) and tropical (16 kg N_2O-N/ha cultivated) organic soils. The uncertainty is determined based on simple error propagation methods (IPCC 2006), including uncertainty in the default emission factor ranging from 2–24 kg N_2O-N/ha (IPCC 2006).

Step 3b: Soil Organic C Stock Changes Due to Drainage of Organic Soils in Cropland and Grassland

Change in soil organic C stocks due to drainage of cropland and grassland soils are estimated for 1982, 1992, 1997, 2002 and 2007, based on the land-use and management activity data in conjunction with appropriate loss rate emission factors. Each input to the inventory for the Tier 2 approach has some level of uncertainty that is quantified in

[90] Reference C stocks are based on cropland soils for the Tier 2 method applied in this Inventory.

PDFs. A Monte Carlo Analysis is used to quantify uncertainty in soil organic C stock changes for the inventory period based on uncertainty in the inputs. Input values are randomly selected from PDFs in an iterative process to estimate SOC change for 50,000 times and produce a 95 percent confidence interval for the inventory results.

Derive Organic Soil Emission Factors: Organic Soil emission factors representative of U.S. conditions have been estimated from published studies (Ogle et al. 2003), based on subsidence studies in the United States and Canada (Table A-232). PDFs are constructed as normal densities based on the mean C loss rates and associated variances.

Estimate Annual C Emissions from Organic Soils: Losses of C are estimated by applying the Monte Carlo approach to 1992, 1997, 2002 and 2007 land-use data from the NRI. The results for 1992 are applied to the years 1990 through 1992, results for 1997 are applied to the years 1993 through 1997, results for 2002 are applied to the years 1998 through 2002, and results for 2007 are applied to the years 2003 through 2011. Losses of soil organic C from drainage of cropland and grassland soils are provided in Table A- 233.

Step 4: Estimate Indirect N_2O Emissions for All Land-Use Types

In this step, N_2O emissions are estimated for the two indirect emission pathways (N_2O emissions due to volatilization, and N_2O emissions due to leaching and runoff of N), which are summed to yield total indirect N_2O emissions from croplands, grasslands, forest lands, and settlements.

Step 4a: Indirect Soil N_2O Emissions Due to Volatilization

Indirect emissions from volatilization of N inputs from synthetic and commercial organic fertilizers, and PRP manure, are calculated according to the amount of mineral N that is transported in gaseous forms from the soil profile and later emitted as soil N_2O following atmospheric deposition. See Step 1e for additional information about the methods used to compute N losses due to volatilization. The estimated N volatilized for all land-use and livestock activities is multiplied by the IPCC default emission factor of 0.01 kg N_2O-N/kg N (IPCC 2006) to estimate total N_2O emissions from volatilization. The uncertainty is estimated using simple error propagation methods (IPCC 2006), by combining uncertainties in the amount of N volatilized, with uncertainty in the default emission factor ranging from 0.002–0.05 kg N_2O-N/kg N (IPCC 2006). The estimates and uncertainties are available in Table A- 233.

Step 4b: Indirect Soil N_2O Emissions Due to Leaching and Runoff

The amount of mineral N from synthetic fertilizers, commercial organic fertilizers, PRP manure, crop residue, N mineralization, asymbiotic fixation that is transported from the soil profile in aqueous form is used to calculate indirect emissions from (1) leaching of mineral N from soils and (2) losses in runoff of water associated with overland flow. See Step 1e for additional information about the methods used to compute N losses from soils due to leaching and runoff in overland water flows.

The total amount of N transported from soil profiles through leaching and surface runoff is multiplied by the IPCC default emission factor of 0.0075 kg N_2O-N/kg N (IPCC 2006) to estimate emissions for this source. The emission estimates are available in Table A-235. The uncertainty is estimated based on simple error propagation methods (IPCC 2006), including uncertainty in the default emission factor ranging from 0.0005 to 0.025 kg N_2O-N/kg N (IPCC 2006).

Step 5: Estimate Total Soil Organic C Stock Changes and N_2O Emissions for U.S. Soils

Step 5a: Estimate Total Soil N_2O Emissions

Total emissions are estimated by adding total direct emissions (from Tier 3 crop types and Tier 1 crop types on mineral cropland soils, drainage and cultivation of organic soils, and grassland management) to indirect emissions for all land use and management activities. Uncertainties in the final estimate are combined using simple error propagation methods (IPCC 2006), and expressed as a 95 percent confidence interval. Estimates and uncertainties are provided in Table A- 231.

Direct and indirect emissions of soil N_2O vary regionally in both croplands and grasslands as a function of N inputs, weather, and soil type. The highest total N_2O emissions from Tier 3 crops occur in Iowa, Illinois, Missouri, Nebraska, Texas, and Kansas (Table A- 237). On a per area unit basis, direct N_2O emissions are high in many of the Mississippi River Basin states where there are high N input to corn and soybean crops, in some western states where irrigated crops requiring high N inputs are grown, and some states in the northeast (Figure A-16). Indirect emissions tend to be high on an area basis in some eastern states because relatively high rainfall facilitates N losses from leaching and runoff and in some Great Plains states where irrigation can contribute to leaching and runoff (Figure A-17).

Direct and indirect emissions from non-federal grasslands are typically lower than those from croplands (Table A- 237, Figure A-18, and Figure A-19) because N inputs tend to be lower, particularly from synthetic fertilizer. Texas and Montana are the highest emitters for this category, followed by Colorado, Oklahoma, and Wyoming. On a per area unit basis, emissions are higher in the Eastern United States because these grasslands are more intensively managed (legume seeding, fertilization) while western rangelands receive few, if any, N inputs. Also, rainfall is limited in most of the western United States, and grasslands are not typically irrigated so minimal leaching and runoff of N occurs in these grasslands, but N volatilization can be substantial.

Figure A-16: Tier 3 Crops,2011 Annual Direct N_2O Emissions, Estimated Using the DAYCENT Model, (kg N./ha/year)

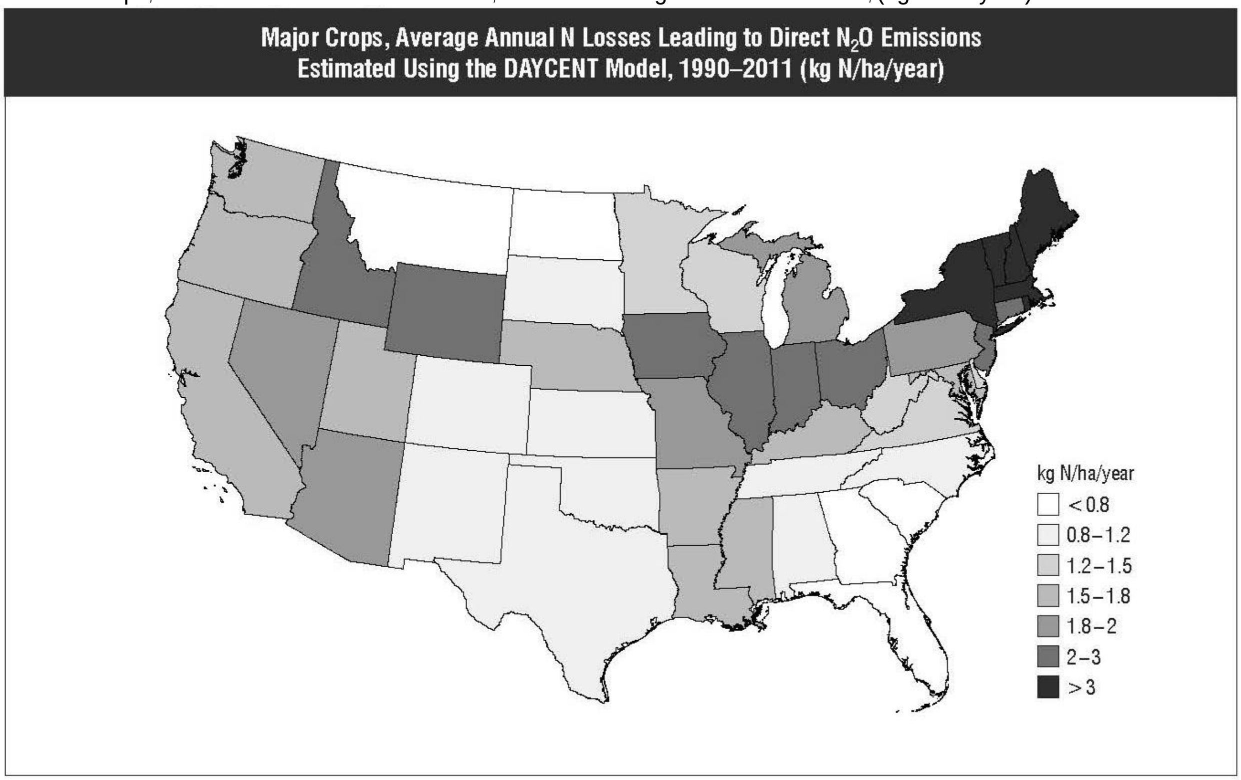


Figure A-17: Tier 3 Crops, 2011 Annual N Losses Leading to Indirect N_2O Emissions, Estimated Using the DAYCENT Model, (kg N/ha/year)

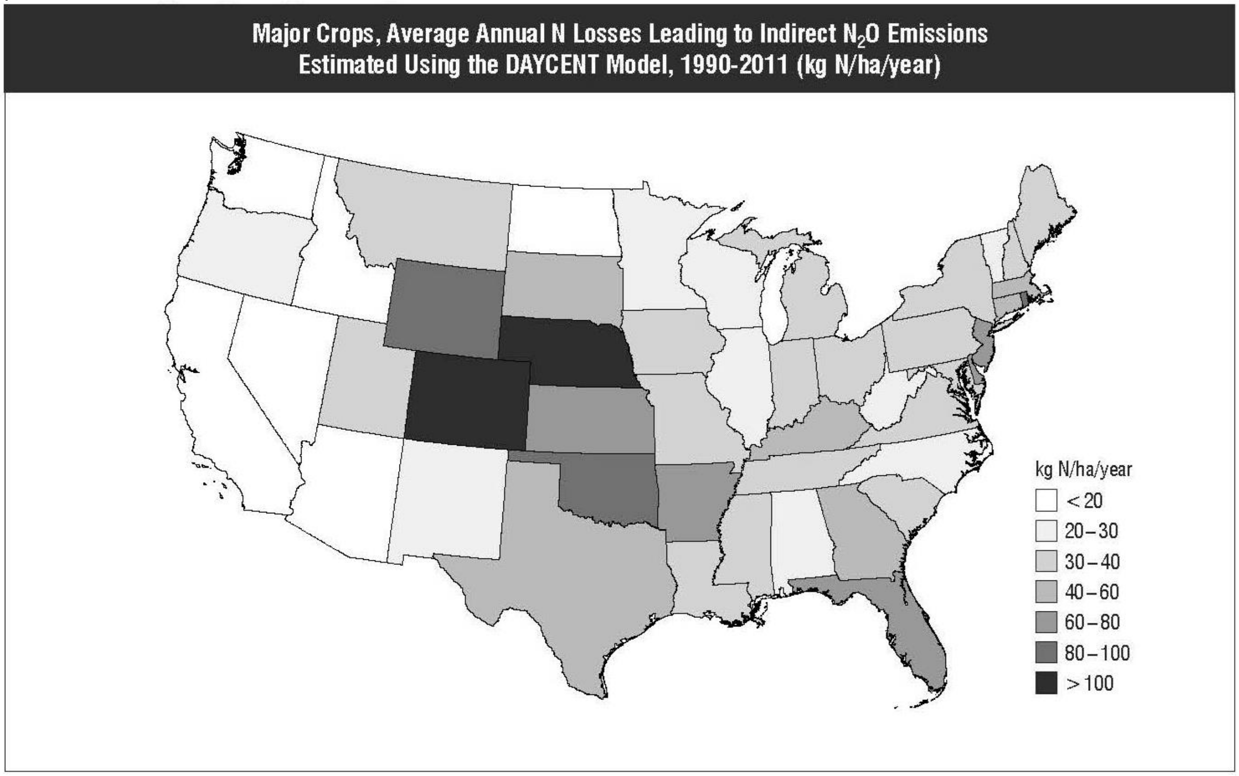


Figure A-18: Non-federal Grasslands, 2011 Annual Direct N_2O Emissions, Estimated Using the DAYCENT Model, (kg N/ha/year)

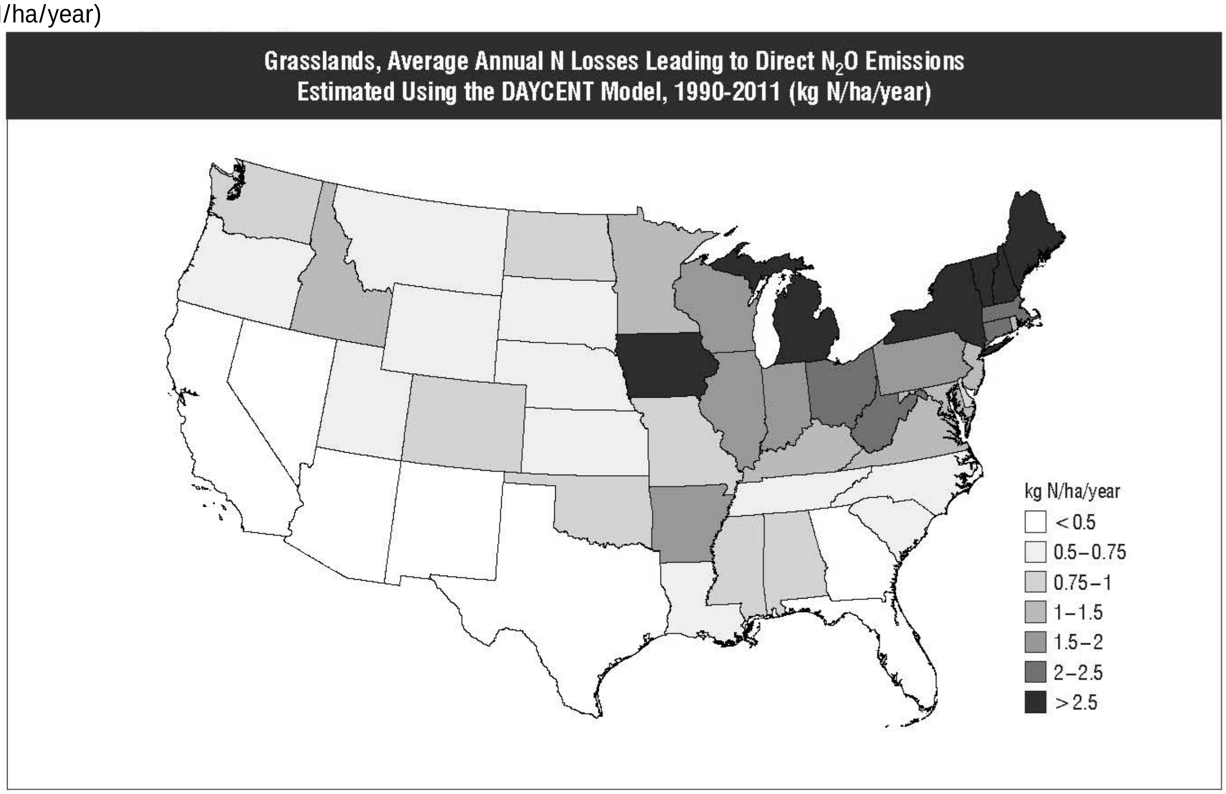
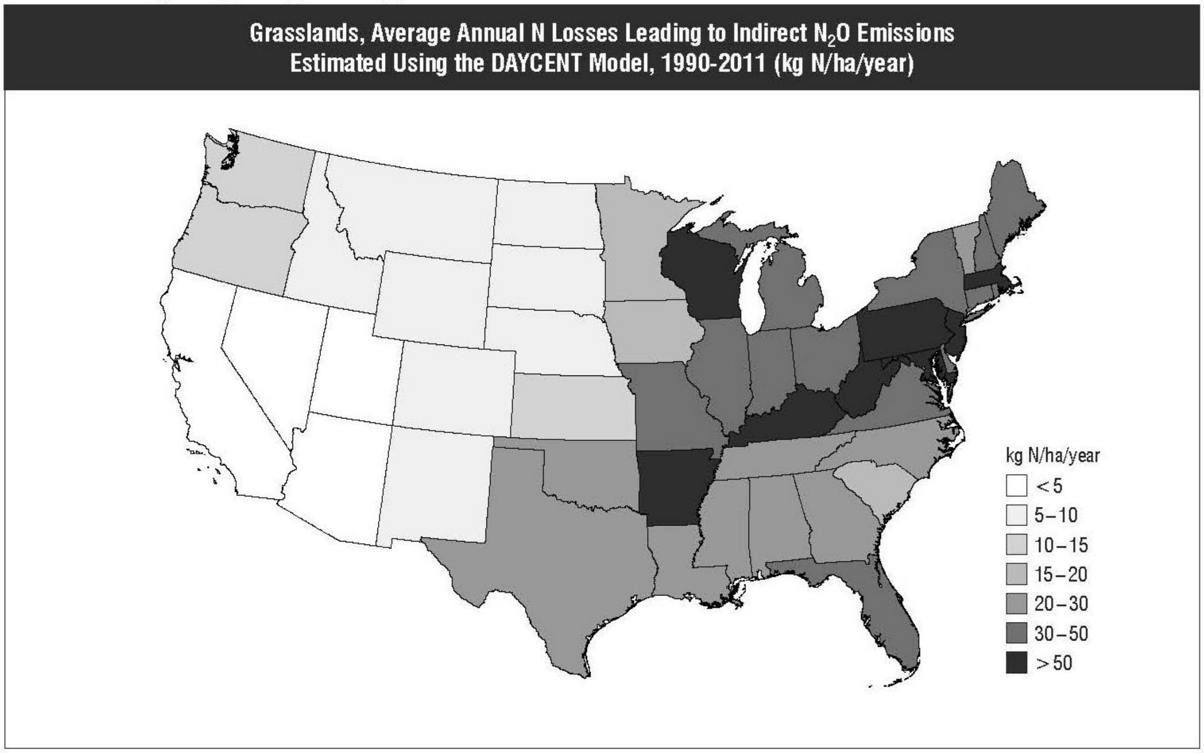


Figure A-19: Non-federal Grasslands, 2011 Annual N Losses Leading to Indirect N_2O Emissions, Estimated Using the DAYCENT Model, (kg N/ha/year)



Step 5b: Estimate Total Soil Organic Stock Change

The sum of total CO_2 emissions and removals from the Tier 3 DAYCENT Model Approach, Tier 2 IPCC Methods and additional land-use and management considerations are provided in Table A-236. The total change in soil organic C stocks (as seen in the Land Use, Land-Use Change, and Forestry chapter) as well as per hectare rate of change varies among the states (Figure A-19 and Figure A-20). The states with highest total amounts of C sequestration are Illinois, Ohio and Kansas (Table A- 238). On a per hectare basis, the highest rates of C accumulation occur in states found in the Southeast, Northeast and Midwest. For organic soils, emission rates are highest in the regions that contain the majority of the drained organic soils, including California, Florida, Michigan, Minnesota, and New York. On a per hectare basis, the emission rate patterns are very similar to the total emissions in each state, with the highest rates in coastal states of the Southeast, states surrounding the Great Lakes, and California.

Figure A-20: Net C Stock Change, per Hectare, for Mineral Soils Under Agricultural Management, 2011

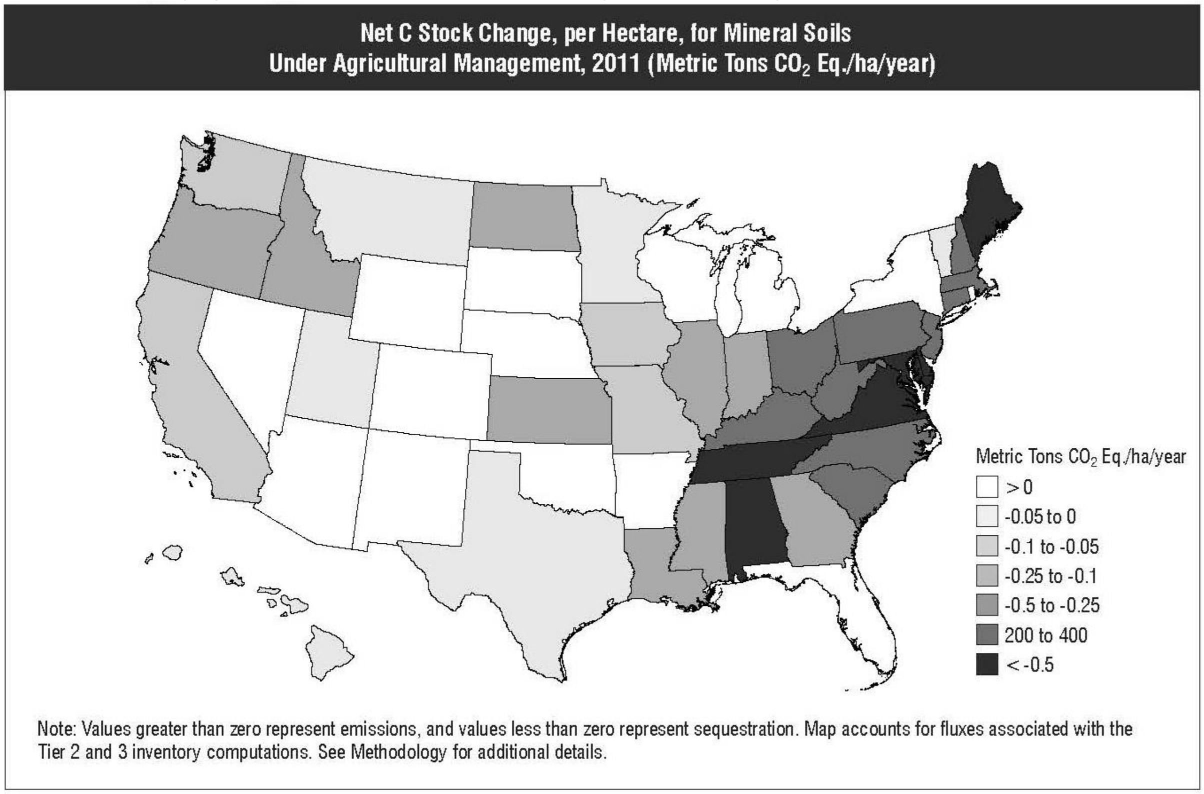


Figure A- 21: Net C Stock Change, per Hectare, for Organic Soils Under Agricultural Management, 2011

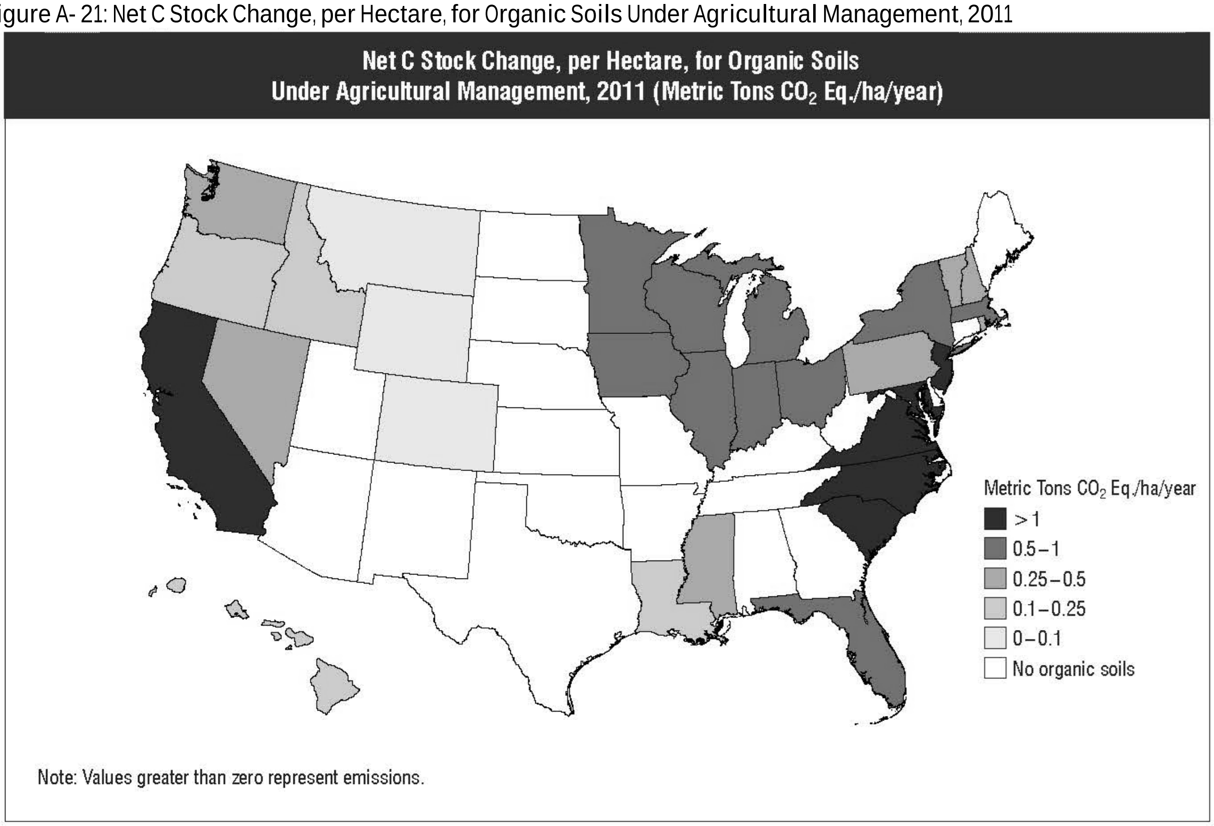


Table A- 231: Assumptions and Calculations to Estimate the Contribution to Soil Organic Carbon Stocks from Application of Sewage Sludge to Mineral Soils

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Sewage Sludge N Applied to Agricultural Land (Mg N)[a]	52,198	55,658	59,250	62,977	65,966	69,001	72,081	75,195	78,353	80,932	83,523	86,124	88,736	91,358	93,991	98,081	100,887	103,682	106,468	109,245	109,245	109,245
Assimilative Capacity (Mg N/ha)[b]	0.120	0.120	0.120	0.122	0.122	0.122	0.122	0.122	0.122	0.122	0.122	0.122	0.122	0.122	0.122	0.122	0.122	0.122	0.122	0.122	0.122	0.122
Area covered by Available Sewage Sludge N (ha)[c]	434,985	463,816	493,746	516,202	540,707	565,583	590,828	616,357	642,240	663,381	684,612	705,932	727,341	748,836	770,418	803,942	826,940	849,851	872,686	895,452	895,452	895,452
Average Annual Rate of C storage (Mg C/ha-yr)[d]	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38
Contribution to Soil C (TgCO2/yr)[e,f]	**(0.61)**	**(0.65)**	**(0.69)**	**(0.72)**	**(0.75)**	**(0.79)**	**(0.82)**	**(0.86)**	**(0.89)**	**(0.92)**	**(0.95)**	**(0.98)**	**(1.01)**	**(1.04)**	**(1.07)**	**(1.12)**	**(1.15)**	**(1.18)**	**(1.22)**	**(1.25)**	**(1.25)**	**(1.25)**

Values in parentheses indicate net C storage.
[a] N applied to soils described in Step 1d.
[b] Assimilative Capacity is the national average amount of manure-derived N that can be applied on cropland without buildup of nutrients in the soil (Kellogg et al., 2000).
[c] Area covered by sewage sludge N available for application to soils is the available N applied at the assimilative capacity rate. The 1992 assimilative capacity rate was applied to 1990 – 1992 and the 1997 rate was applied to 1993-2009.
[d] Annual rate of C storage based on national average increase in C storage for grazing lands that is attributed to organic matter amendments (0.38 Mg/ha-yr)
[e] Contribution to Soil C is estimated as the product of the area covered by the available sewage sludge N and the average annual C storage attributed to an organic matter amendment.
[f] Some small, undetermined fraction of this applied N is probably not applied to agricultural soils, but instead is applied to forests, home gardens, and other lands.

Table A-232: Carbon Loss Rates for Organic Soils Under Agricultural Management in the United States, and IPCC Default Rates (Metric Ton C/ha-yr)

	Cropland		Grassland	
Region	**IPCC**	**U.S. Revised**	**IPCC**	**U.S. Revised**
Cold Temperate, Dry & Cold Temperate, Moist	1	11.2±2.5	0.25	2.8±0.5[a]
Warm Temperate, Dry & Warm Temperate, Moist	10	14.0±2.5	2.5	3.5±0.8[a]
Sub-Tropical, Dry & Sub-Tropical, Moist	1	11.2±2.5	0.25	2.8±0.5[a]

[a] There are not enough data available to estimate a U.S. value for C losses from grassland. Consequently, estimates are 25 percent of the values for cropland, which is an assumption that is used for the IPCC default organic soil C losses on grassland.

Table A- 233: Indirect N_2O Emissions from Volatilization (Tg CO_2 Eq.)

Activity	1990	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Croplands	13.1	14.5	14.4	14.5	14.7	14.3	14.2	14.1	14.3	13.9	14.9	14.3	15.0	14.4	14.0	13.8	13.9	14.0
Settlements	0.1	0.2	0.2	0.2	0.1	0.1	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Forest Land	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Grasslands	7.3	8.0	7.8	7.8	7.8	7.4	7.3	7.3	7.3	7.5	7.9	7.8	7.6	7.8	7.7	7.7	7.6	7.6
Total	**20.6**	**22.7**	**22.4**	**22.5**	**22.7**	**21.9**	**21.7**	**21.7**	**21.8**	**21.6**	**23.0**	**22.4**	**22.8**	**22.4**	**22.0**	**21.7**	**21.8**	**21.8**

+ Less than 0.05 Tg CO_2 Eq.

Table A- 234: Indirect N2O Emissions from Leaching and Runoff (Tg CO2 Eq.)

Activity	1990	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Croplands	20.2	25.8	24.5	20.3	20.2	23.4	13.5	16.4	15.8	12.6	23.5	14.1	12.5	27.1	26.2	25.6	26.3	26.4
Settlements	0.2	0.3	0.3	0.3	0.3	0.3	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
Forest Land	+	+	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Grasslands	5.0	5.4	6.2	5.0	5.9	4.8	5.6	5.2	5.6	4.9	4.6	4.8	5.9	3.8	3.7	3.7	3.6	3.3
Total	**25.4**	**31.6**	**31.1**	**25.6**	**26.4**	**28.6**	**19.6**	**22.1**	**22.0**	**18.0**	**28.6**	**19.3**	**18.9**	**31.4**	**30.4**	**29.8**	**30.4**	**30.2**

+ Less than 0.05 Tg CO_2 Eq.

Table A-235: Total N_2O Emissions from Agricultural Soil Management (Tg CO_2 Eq.)

Activity	1990	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Total Direct	**181.8**	**200.3**	**212.0**	**212.4**	**192.4**	**190.8**	**185.7**	**193.6**	**196.9**	**194.1**	**197.0**	**195.8**	**201.5**	**198.5**	**193.0**	**191.3**	**192.3**	**195.2**
Direct Emissions from Mineral Cropland Soils	**101.0**	**121.4**	**131.2**	**128.7**	**111.0**	**117.0**	**106.5**	**116.9**	**113.8**	**112.7**	**120.7**	**121.8**	**122.9**	**125.6**	**121.7**	**119.5**	**122.1**	**122.5**
Synthetic Fertilizer	40.0	47.5	53.6	53.5	44.6	49.0	44.5	44.7	44.7	45.4	47.5	49.1	48.6	53.0	49.5	47.5	49.9	50.3
Organic Amendment[a]	11.6	13.2	13.5	13.6	12.5	13.0	12.7	13.2	13.3	12.5	13.1	13.5	13.9	14.0	13.8	13.7	13.7	13.7
Residue N[b]	3.7	4.4	4.6	4.5	3.7	4.2	3.6	4.1	3.6	3.9	4.4	4.3	3.9	4.2	4.1	4.1	4.1	4.1
Mineralization and Asymbiotic Fixation	45.8	56.3	59.4	57.2	50.1	50.8	45.8	54.9	52.1	50.9	55.7	55.0	56.5	54.5	54.4	54.3	54.4	54.4
Direct Emissions from Drained Organic Cropland Soils	**2.9**	**2.9**	**2.9**	**2.9**	**2.9**	**2.9**	**2.9**	**2.9**	**2.9**	**2.9**	**2.9**	**2.9**	**2.9**	**2.9**	**2.9**	**2.9**	**2.9**	**2.9**
Direct Emissions from Grasslands	**77.9**	**76.0**	**78.0**	**80.8**	**78.6**	**70.9**	**76.3**	**73.8**	**80.2**	**78.4**	**73.4**	**71.1**	**75.7**	**69.9**	**68.4**	**68.9**	**67.3**	**69.8**
Synthetic Mineral Fertilizer	3.0	2.4	2.7	2.7	2.7	2.6	2.6	2.5	3.1	3.0	2.8	2.9	3.0	2.7	2.4	2.5	2.2	2.1
PRP Manure	27.7	29.4	30.6	28.9	29.4	27.6	28.2	27.1	29.3	27.8	24.9	25.7	28.4	23.4	22.6	22.4	22.0	21.8
Managed Manure	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Sewage Sludge	0.3	0.3	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.6
Residue[b]	2.7	2.9	3.1	3.1	3.0	2.5	2.5	2.7	2.9	2.9	2.7	2.7	2.8	2.7	2.8	2.8	2.7	2.9
Mineralization and Asymbiotic Fixation	44.2	40.8	41.1	45.5	42.9	37.7	42.4	41.0	44.4	44.2	42.4	39.2	40.8	40.5	40.0	40.5	39.8	42.3
Total Indirect	**46.0**	**54.3**	**53.4**	**48.1**	**49.1**	**50.6**	**41.2**	**43.8**	**43.7**	**39.6**	**51.6**	**41.7**	**41.7**	**53.8**	**52.4**	**51.5**	**52.2**	**51.9**
Volatilization	20.6	22.7	22.4	22.5	22.7	21.9	21.7	21.7	21.8	21.6	23.0	22.4	22.8	22.4	22.0	21.7	21.8	21.8
Leaching/Runoff	25.4	31.6	31.1	25.6	26.4	28.6	19.6	22.1	22.0	18.0	28.6	19.3	18.9	31.4	30.4	29.8	30.4	30.2
Total Emissions	**227.9**	**254.6**	**265.4**	**260.5**	**241.5**	**241.4**	**227.0**	**237.4**	**240.6**	**233.7**	**248.6**	**237.5**	**243.2**	**252.3**	**245.4**	**242.8**	**244.5**	**247.2**

+ Less than 0.05 Tg CO_2 Eq.

[a] Organic amendment inputs include managed manure amendments, daily spread manure and other commercial organic fertilizer (i.e., dried blood, tankage, compost, and other).

[b] Residue N inputs include unharvested fixed N from legumes as well as crop residue N.

Table A-236: Annual Soil C Stock Change in *Cropland Remaining Cropland* (CRC), *Land Converted to Cropland* (LCC), *Grassland Remaining Grassland* (GRG), and *Land Converted to Grassland* (LCG), in U.S. Agricultural Soils (Tg CO_2 Eq.)

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Net emissions based on Tier 3 DAYCENT-based analysis (Step 2)																						
CRC	(53.9)	(62.2)	(54.3)	(54.3)	(59.0)	(43.2)	(49.7)	(53.7)	(42.1)	(44.6)	(53.9)	(36.2)	(26.7)	(24.3)	(30.8)	(44.3)	(28.3)	(30.6)	(30.6)	(30.6)	(30.6)	(30.6)
LCC	14.1	11.3	13.1	12.7	6.5	13.7	12.3	13.7	8.1	9.5	10.2	10.4	14.1	12.2	10.7	10.9	11.7	11.8	11.8	11.8	11.8	11.8
GRG	(7.9)	(10.7)	(11.2)	(6.9)	(20.3)	(4.5)	(19.4)	(11.8)	(11.9)	(4.9)	(37.0)	(8.6)	(12.9)	(7.2)	(2.9)	(2.8)	(15.3)	5.5	5.5	5.6	5.7	5.8
LCG	(4.6)	(5.8)	(4.8)	(5.8)	(6.8)	(6.2)	(7.6)	(7.0)	(7.3)	(8.0)	(9.4)	(8.8)	(8.3)	(8.2)	(8.4)	(8.5)	(9.5)	(7.3)	(7.3)	(7.2)	(7.1)	(7.1)
Net emissions based on the IPCC Tier 2 analysis (Step 3)																						

Mineral Soils																						
CRC	(6.5)	(6.5)	(6.5)	(7.6)	(7.6)	(7.6)	(7.6)	(7.6)	(6.9)	(6.9)	(6.9)	(6.9)	(6.9)	(2.8)	(2.8)	(2.8)	(2.8)	(2.8)	(2.8)	(2.8)	(2.8)	(2.8)
LCC	4.8	4.8	4.8	4.7	4.7	4.7	4.7	4.7	3.7	3.7	3.7	3.7	3.7	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
GRG	(0.2)	(0.2)	(0.2)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
LCG	(3.5)	(3.5)	(3.5)	(3.6)	(3.6)	(3.6)	(3.6)	(3.6)	(3.6)	(3.6)	(3.6)	(3.6)	(3.6)	(2.5)	(2.5)	(2.5)	(2.5)	(2.5)	(2.5)	(2.5)	(2.5)	(2.5)
Organic Soils																						
CRC	26.3	26.3	26.3	25.7	25.7	25.7	25.7	25.7	25.7	25.7	25.7	25.7	25.7	26.8	26.8	26.8	26.8	26.8	26.8	26.8	26.8	26.8
LCC	2.2	2.2	2.2	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1
GRG	3.4	3.4	3.4	3.0	3.0	3.0	3.0	3.0	2.6	2.6	2.6	2.6	2.6	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8
LCG	0.4	0.4	0.4	0.7	0.7	0.7	0.7	0.7	0.9	0.9	0.9	0.9	0.9	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
Additional changes in net emissions from mineral soils based on application of sewage sludge to agricultural land (Step 4)																						
GRG	(0.6)	(0.6)	(0.7)	(0.7)	(0.8)	(0.8)	(0.8)	(0.9)	(0.9)	(0.9)	(1.0)	(1.0)	(1.0)	(1.0)	(1.1)	(1.1)	(1.2)	(1.2)	(1.2)	(1.2)	(1.2)	(1.2)
Additional changes in net emissions from mineral soils based on additional enrollment of CRP land (Step 4)																						
CRC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1.4	2.0	3.6	3.7
Total Stock Changes by Land Use/Land-Use Change Category (Step 5)																						
CRC	(34.1)	(42.4)	(34.5)	(36.3)	(41.0)	(25.2)	(31.7)	(35.6)	(23.4)	(25.9)	(35.2)	(17.5)	(8.0)	(0.4)	(6.9)	(20.3)	(4.4)	(6.6)	(5.2)	(4.6)	(3.0)	(2.9)
LCC	21.0	18.3	20.0	19.9	13.7	20.9	19.5	20.9	14.4	15.7	16.5	16.7	20.4	14.9	13.4	13.5	14.4	14.5	14.5	14.5	14.5	14.5
GRG	(5.3)	(8.1)	(8.7)	(4.7)	(18.1)	(2.3)	(17.3)	(9.7)	(10.2)	(3.2)	(35.3)	(7.0)	(11.4)	(5.3)	(1.1)	(1.0)	(13.6)	7.1	7.2	7.3	7.3	7.4
LCG	(7.7)	(8.9)	(7.8)	(8.6)	(9.6)	(9.0)	(10.4)	(9.8)	(10.1)	(10.8)	(12.1)	(11.6)	(11.1)	(9.9)	(10.1)	(10.2)	(11.2)	(9.0)	(9.0)	(8.9)	(8.8)	(8.8)
Total	**(26.0)**	**(41.2)**	**(31.1)**	**(29.8)**	**(55.0)**	**(15.6)**	**(39.9)**	**(34.3)**	**(29.2)**	**(24.2)**	**(66.1)**	**(19.4)**	**(10.0)**	**(0.7)**	**(4.7)**	**(18.0)**	**(14.8)**	**6.0**	**7.6**	**8.3**	**10.0**	**10.3**

Note: Totals may not sum due to independent rounding.

Table A- 237: Total 2011 N_2O Emissions (Direct and Indirect) from Agricultural Soil Management by State (Tg CO_2 Eq.)

State	Croplands[a]	Grasslands[b]	Settlements[c]	Forest Lands[d]		Total	Lower Bound	Upper Bound
AL	0.93	1.01	0.03	n.e.		2.01	1.10	3.89
AR	3.57	1.80	0.02	n.e.		5.46	3.92	8.45
AZ	0.90	1.18	0.01	n.e.		2.15	0.99	4.28
CA	3.89	1.71	0.19	n.e.		6.06	3.75	10.64
CO	6.17	4.21	0.02	n.e.		10.59	7.34	17.93
CT	0.86	0.05	0.02	n.e.		0.98	0.50	2.59
DE	0.17	0.01	0.01	n.e.		0.20	0.14	1.15
FL	2.03	1.09	0.23	n.e.		3.43	2.01	5.87
GA	0.87	0.77	0.01	n.e.		1.68	0.85	3.56
HI[e]	0.00	n.e.	n.e.	n.e.		0.03	0.01	0.11
IA	12.94	2.96	0.07	n.e.		16.03	12.27	22.88
ID	3.25	2.25	0.02	n.e.		5.60	4.10	8.64
IL	11.56	0.96	0.12	n.e.		12.66	10.17	16.83
IN	6.55	0.72	0.08	n.e.		7.38	5.59	10.70
KS	10.53	3.78	0.07	n.e.		14.44	10.33	22.40
KY	1.97	1.72	0.03	n.e.		3.76	2.73	5.98
LA	1.84	0.49	0.04	n.e.		2.38	1.74	3.92
MA	0.18	0.04	0.04	n.e.		0.26	0.19	1.10
MD	0.69	0.17	0.05	n.e.		0.94	0.62	2.10
ME	0.37	0.11	0.01	n.e.		0.49	0.33	1.41
MI	4.03	1.08	0.08	n.e.		5.25	3.90	8.22
MN	7.59	1.39	0.04	n.e.		9.09	7.04	13.26
MO	6.40	3.06	0.07	n.e.		9.56	7.00	13.78
MS	2.33	0.77	0.03	n.e.		3.16	2.36	4.99
MT	3.81	6.05	0.01	n.e.		9.89	6.61	14.27
NC	1.84	0.67	0.05	n.e.		2.65	0.99	5.85
ND	4.77	2.19	0.03	n.e.		7.00	5.61	9.41
NE	13.42	3.70	0.07	n.e.		17.24	8.90	32.29
NH	0.11	0.03	0.01	n.e.		0.15	0.09	1.12
NJ	0.23	0.05	0.08	n.e.		0.36	0.27	1.30
NM	1.30	3.19	0.01	n.e.		4.57	2.09	8.08
NV	0.27	0.88	0.01	n.e.		1.17	0.81	2.26
NY	4.00	1.33	0.07	n.e.		5.45	4.15	8.05
OH	7.04	0.93	0.11	n.e.		8.25	5.84	12.32
OK	3.63	4.90	0.03	n.e.		8.60	5.68	13.50
OR	1.42	1.66	0.01	n.e.		3.10	2.36	4.65
PA	2.66	0.74	0.06	n.e.		3.51	2.63	5.73
RI	0.02	0.01	0.01	n.e.		0.03	0.02	0.84
SC	0.55	0.33	0.03	n.e.		0.94	0.52	2.21
SD	5.26	3.64	0.02	n.e.		8.94	5.70	13.43
TN	1.31	1.27	0.05	n.e.		2.66	1.77	4.71
TX	9.94	7.11	0.09	n.e.		17.27	9.78	27.65
UT	0.81	1.33	0.01	n.e.		2.16	1.58	3.63
VA	0.93	1.44	0.06	n.e.		2.43	1.39	4.38
VT	0.72	0.20	0.00	n.e.		0.92	0.69	1.95
WA	3.12	1.38	0.03	n.e.		4.58	3.50	6.69
WI	4.91	1.52	0.04	n.e.		6.59	4.08	11.55
WV	0.24	0.41	0.01	n.e.		0.66	0.47	1.64
WY	1.64	3.62	0.01	n.e.		5.31	4.28	3.58

[a] Emissions from non-manure organic N inputs for minor crops were not estimated (n.e.) at the state level.
[b] Emissions from sewage sludge applied to grasslands and were not estimated (n.e.) at the state level
[c] Emissions from sewage sludge applied to settlements were not estimated (n.e.) at the state level.
[d] Forestland emissions were not estimated (n.e.) at the state level.
[e] N_2O emissions are not reported for Hawaii except from cropland organic soils.

Table A- 238: Soil C Stock Change for Mineral and Organic Soils during 2011 within individual states (Tg CO_2 Eq.)

State	Mineral Soil	Organic Soil	Total
AL	(1.45)	-	(1.45)
AR	0.48	-	0.48

AZ	0.73	-	0.73
CA	(0.87)	2.29	1.42
CO	1.08	0.00	1.08
CT	(0.03)	-	(0.03)
DE	(0.19)	-	(0.19)
FL	0.49	10.84	11.32
GA	(0.55)	-	(0.55)
HI	-	0.25	0.25
IA	(1.15)	0.75	(0.40)
ID	(0.71)	0.11	(0.61)
IL	(2.39)	0.54	(1.84)
IN	(1.30)	2.93	1.63
KS	(3.05)	-	(3.05)
KY	(1.94)	-	(1.94)
LA	(0.37)	0.07	(0.31)
MA	(0.05)	0.03	(0.01)
MD	(0.69)	0.03	(0.66)
ME	(0.12)	-	(0.12)
MI	0.10	2.72	2.82
MN	(0.05)	7.30	7.24
MO	(0.70)	-	(0.70)
MS	(0.39)	0.00	(0.39)
MT	(0.31)	0.11	(0.20)
NC	(1.27)	2.25	0.99
ND	(1.76)	-	(1.76)
NE	1.78	-	1.78
NH	(0.04)	0.01	(0.03)
NJ	(0.20)	0.01	(0.20)
NM	0.45	-	0.45
NV	0.05	0.00	0.05
NY	0.15	0.61	0.75
OH	(2.11)	0.42	(1.70)
OK	0.59	-	0.59
OR	(1.00)	0.12	(0.88)
PA	(0.85)	0.01	(0.83)
RI	0.00	0.00	0.01
SC	(0.50)	0.04	(0.46)
SD	2.22	-	2.22
TN	(1.94)	-	(1.94)
TX	(0.95)	-	(0.95)
UT	(0.12)	-	(0.12)
VA	(1.71)	0.02	(1.69)
VT	(0.02)	0.00	(0.02)
WA	(0.54)	0.26	(0.28)
WI	0.98	2.88	3.87
WV	(0.46)	-	(0.46)
WY	0.70	0.01	0.71

Note: Parentheses indicate net C accumulation. Estimates do not include soil C stock change associated with CRP enrollment after 2007 or sewage sludge application to soils, which were only estimated at the national scale. The sum of state results will not match the national results because state results are generated in a separate programming package, the sewage sludge and CRP enrollment after 2007 are not included, and differences arise due to rounding of values in this table.

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