USER'S GUIDE FOR ESTIMATING CARBON DIOXIDE, METHANE, AND NITROUS OXIDE EMISSIONS FROM AGRICULTURE USING THE STATE INVENTORY TOOL

JANUARY 17, 2025

Prepared by:
ICF

Prepared for:
State Energy and Environment Program,
U.S. Environmental Protection Agency

This section of the User's Guide provides instruction on using the CO_2, CH_4, and N_2O from Agriculture (Ag) module of the State Inventory Tool (SIT), and describes the methodology used for estimating greenhouse gas emissions from agriculture at the state level.

TABLE OF CONTENTS

1.1 Getting Started 2

1.2 Module Overview 3

1.2.1 Data Requirements 5

1.2.2 Tool Layout 6

1.3 Methodology 6

1.4 Uncertainty 30

1.5 References 30

1.1 GETTING STARTED

The Agriculture (Ag) module of the State Inventory Tool (SIT) was first developed using Microsoft® Excel 2000. While the module will operate with older versions of Excel, it functions best with Excel 2000 or later. Some of the Excel basics are outlined in the sections below. Before you use the Ag module, make sure your computer meets the system requirements. In order to install and run the Ag module, you must have:

- IBM-PC compatible computer with the Windows 95 operating system or later;
- Microsoft® Excel 1997 or later, with calculation set to automatic and macros enabled;
- Hard drive with at least 20MB free; and
- Monitor display setting of 800 x 600 or greater.

Microsoft Excel Settings

Excel 2003 and Earlier: For the SIT modules to function properly, Excel must be set to automatic calculation. To check this setting, launch Microsoft Excel before opening the Ag module. Go to the Tools menu and select "Options..." Click on the "Calculations" tab and make sure that the radio button next to "Automatic" is selected, and then click on "OK" to close the window. The security settings (discussed next) can also be adjusted at this time.

Excel 2007 and Later: For the SIT modules to function properly, Excel must be set to automatic calculation. Go to the Formulas ribbon and select "Calculation Options." Make sure that the box next to the "Automatic" option is checked from the pop-up menu.

Microsoft Excel Security

Excel 2003 and Earlier: Because the SIT employs macros, you must have Excel security set to medium (recommended) or low (not recommended). To change this setting, launch Microsoft Excel before opening the Ag module. Once in Excel, go to the Tools menu, click on the Macro sub-menu, and then select "Security" (see Figure 1). The Security pop-up box will appear. Click on the "Security Level" tab and select medium. When set to high, macros are automatically disabled; when set to medium, Excel will give you the choice to enable macros; when set to low, macros are always enabled.

When Excel security is set to medium, users are asked upon opening the module whether to enable macros. Macros must be enabled in order for the Ag module to work. Once they are enabled, the module will open to the control worksheet. A message box will appear welcoming the user to the module. Clicking on the "x" in the upper-right-hand corner of the message box will close it.

Excel 2007 and Later: If Excel's security settings are set at the default level a Security Warning appears above the formula box in Excel when the Ag module is initially opened. The Security Warning lets the user know that some active content from the spreadsheet has been disabled, meaning that Excel has prevented the macros in the spreadsheet from functioning. Because SIT needs macros in order to function properly, the user must click the "Options" button in the security message and then select, "Enable this content" in the pop-up box. Enabling the macro content for the SIT in this way only enables macros temporarily in Excel but does not change the macro security settings. Once macros are enabled, a message box will appear welcoming the user to module. Click on the "x" in the upper right-hand corner to close the message box.

If the Security Warning does not appear when the module is first opened, it may be necessary to change the security settings for macros. To change the setting, first exit out of the Ag module and re-launch Microsoft Excel before opening the Ag module. Next, click on the Microsoft Excel icon in the top left of the screen. Scroll to the bottom of the menu and select the "Excel Options" button to the right of the main menu. When the Excel Options box appears, select "Trust Center" in left hand menu of the box. Next, click the gray "Trust Center Settings" button. When the Trust Center options box appears, click "Macro Settings" in the left-hand menu and select "Disable all macros with notification." Once the security level has been adjusted, open the Stationary Combustion module and enable macros in the manner described in the preceding paragraph.

Viewing and Printing Data and Results

The Ag module contains some features to allow users to adjust the screen view and the appearance of the worksheets when they are printed. Once a module has been opened, you can adjust the zoom by going to the Module Options Menu, and either typing in a zoom percentage or selecting one from the drop-down menu. In addition, data may not all appear on a single screen within each worksheet; if not, you may need to scroll up or down to view additional information.

You may also adjust the print margins of the worksheets to ensure that desired portions of the Ag module are printed. To do so, go to the File menu, and then select "Print Preview." Click on "Page Break Preview" and drag the blue lines to the desired positions (see Figure 2). To print this view, go to the File menu, and click "Print." To return to the normal view, go to the File menu, click "Print Preview," and then click "Normal View."

Figure 1. Changing Security Settings

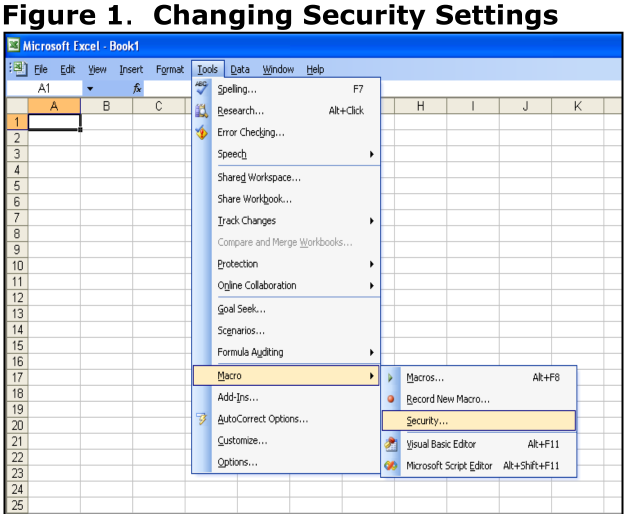
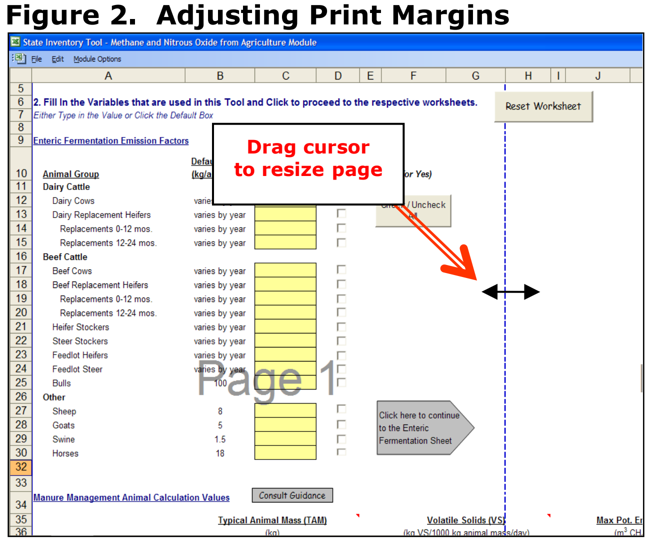


Figure 2. Adjusting Print Margins



1.2 Module Overview

This User's Guide accompanies and explains the Agriculture module of the SIT. The SIT was originally developed in conjunction with EPA's Emissions Inventory Improvement Program (EIIP) in order to automate the steps states would need to take in developing their own emission estimates in a manner that was consistent with prevailing national and state guidelines. The result was a user-friendly and comprehensive set of eleven modules that help users estimate greenhouse gas emissions at the state level.

Because most state inventories developed today rely heavily on the SIT, User's Guides have been developed for each of the SIT modules. These User's Guides contain the most up-to-date methodologies that are, for the most part, consistent with the Inventory of U.S. Greenhouse Gas Emissions and Sinks (EPA 2024a). Users can refer to the chapters and annexes of the U.S. Inventory to obtain additional information not found in the SIT or in the companion User's Guide.

In 2024, EPA published the results of the 2022 Inventory of U.S. Greenhouse Gas Emissions and Sinks disaggregated by U.S. state (2024b). to make consistent state-level GHG data available for all states for use by states, researchers, and the general public. However, EPA recognizes that there will be differences between the state-level estimates published by EPA and inventory estimates developed by states using the SIT or other tools. Inventories compiled by states may differ for several reasons, and differences do not necessarily mean that one set of estimates is more accurate, or "correct." In some cases, the Inventory of U.S. Greenhous Gas Emissions and Sinks may be using different methodologies, activity data, and emission factors, or may have access to the latest facility-level information through the Greenhouse Gas Reporting Program (GHGRP). In other cases, because of state laws and regulations, states may have adopted accounting decisions that differ from those adopted by UNFCCC and IPCC to ensure comparability in national reporting (e.g., use of different category definitions and emission scopes consistent with state laws and regulations). Users of state GHG data should take care to review and understand differences in accounting approaches to ensure that any comparisons of estimates are equivalent or an apples-to-apples comparison of estimates.

The Ag module calculates carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) emissions from the agricultural sectors shown in Table 1. The Ag module now estimates CO_2 emissions from Liming of Soils and Urea Fertilization for consistency with the Inventory of U.S. Greenhouse Gas Emissions and Sinks. These categories were previously estimated in the Land Use, Land-Use Change, and Forestry module.

While the module provides default data for each sector (depending on availability), users are encouraged to use state-specific data, where available. If using outside data sources, or for a more thorough understanding of the tool, please refer to the following discussion for data requirements and methodology.

1.2.1 Data Requirements

To calculate CO_2, CH_4, and N_2O emissions from agriculture, general animal and crop production and emission characteristics are required. A complete list of the activity data and emission factors necessary to run the Ag module is provided in Table 1.

Table 1. Agricultural Sectors, Data Requirements, and Gases Emitted

Module Worksheet	**Data Required**	**Gas(es)**
Enteric Fermentation	Emission Factors by Animal Type Animal Population Numbers	CH_4
Manure Management-CH_4 Manure Management-N_2O	Typical Animal Mass (TAM) Volatile Solids (VS) Production Maximum Potential CH_4 Emissions (B_o) Kjeldahl (K) Nitrogen Excreted* Animal Population Numbers	CH_4, N_2O
Ag Soils-Plant-Residues & Legumes Ag Soils-Plant-Fertilizers Ag Soils- Animals	Residue Dry Matter Fraction Fraction Residue Applied Nitrogen Content of Residue Kjeldahl (K) Nitrogen Excreted Crop Production Fertilizer Utilization TAM*	N_2O
Rice Cultivation	Seasonal Emission Factor Area Harvested	CH_4
Liming of Soils	Emission factors for CO_2 emitted from use of crushed limestone and dolomite (ton C/ton limestone) Total limestone and dolomite applied to soils (metric tons)	CO_2
Urea Fertilization	Emission factors for CO_2 emitted from the use of urea as a fertilizer (tons C/ton urea) Total urea applied to soils (metric tons)	CO_2
Ag. Residue Burning-CH_4 Ag. Residue Burning-N_2O	Residue/Crop Ratio Fraction of Residue Burned Dry Matter Fraction* Burning Efficiency Combustion Efficiency Carbon Content Nitrogen Content*	CH_4, N_2O

* For consistency in calculations, data that overlaps between sectors are pulled through from the original input into subsequent uses.

1.2.2 Tool Layout

Because there are multiple steps to complete within the Ag module, it is important to have an understanding of the module's overall design. The layout of the Ag module and the purpose of its worksheets are presented in Figure 3.

Figure 3. Flow of Information in the Ag Module*

Control Worksheet	Individual Sector Worksheets
1. Choose a State	
2. to 6. Enter Emission Factors and Activity Data for: Enteric Fermentation Manure Management Ag Soils Rice Cultivation Liming of Soils Urea Fertilization Ag Residue Burning	**2. Enteric Fermentation** Enter animal population data for each year **3a. CH_4 from Manure Management** Enter animal population data for each year **3b. N_2O from Manure Management** Review data imported from Manure CH_4 worksheet **4a. Ag Soils-Plant-Residues & Legumes** Enter crop production data for each year **4b. Ag Soils-Plant-Fertilizers** Enter fertilizer use by calendar year or growing year **4c. Ag Soils-Animals** Review data imported from Manure CH_4 worksheet **5. Rice Cultivation** Enter data harvested for each year **6. Liming of Soils** Enter data on amount of limestone and dolomite applied to soils **7. Urea Fertilization** Enter data on amount of urea applied to soils **8a. Ag. Reside Burning-CH_4** Enter crop data and activity data for non-default crops **8b. Ag Residue Burning-N_2O** Enter nitrogen content for non-default crops
9. View Summary Data	**Summary Data** Presented in both table and graphical formats in $MMTCO_2E$.
10. Export Data	**Uncertainty** Review information on uncertainty associated with default data.

* These worksheets are the primary worksheets used in the Ag module; subsequent worksheets are used to populate the default data and are provided for informational purposes only.

1.3 Methodology

This section provides a guide to using the Ag module of the SIT to estimate CO_2, CH_4, and N_2O emissions from livestock and crop production. Within the Ag module the sectors included are enteric fermentation, manure management, agricultural soils, rice cultivation, liming of soils, urea fertilization, and agricultural residue burning. Because the methodology differs for each sector, they are discussed separately and specific examples for each sector are provided.

The Ag module automatically calculates emissions after you enter or choose default data for the factors on the control worksheet and the activity data within each sector worksheet. The tool provides default data for most required information; however, other more state-specific data may be used if available. Additionally, for some states data may not be available for all crop or livestock types, so users should check each worksheet to determine if additional information may be available.

The Ag module follows the general methodology from the National Inventory Report (NIR) GHG Inventory by U.S. State, with the exception of the Rice Cultivation and Agricultural Soil Management categories. For both of these sections, the NIR uses a combination of IPCC Tier

1 and Tier 3 approaches, while the SIT Ag module only utilizes a Tier 1 approach for Agricultural Soil Management and utilizes a seasonal emissions factor for Rice Cultivation.

This User's Guide provides an overview of the estimation methodology used in the Ag module by walking through the following steps: (1) select a state; (2) enter emission factors and activity data for enteric fermentation; (3) enter emission factors and activity data for manure management; (4) enter emission factors and activity data for agricultural soils; (5) enter emission factors and activity data for rice cultivation; (6) enter emission factors and activity data for liming of soils; (7) enter emission factors and activity data for urea fertilization; (8) enter emission factors and activity data for agricultural residue burning; (9) review summary information; and (10) export data. The general equations used to calculate CO_2, CH_4, and N_2O emissions from agriculture are shown in the discussion of each specific sector.

Step (1) Select a State

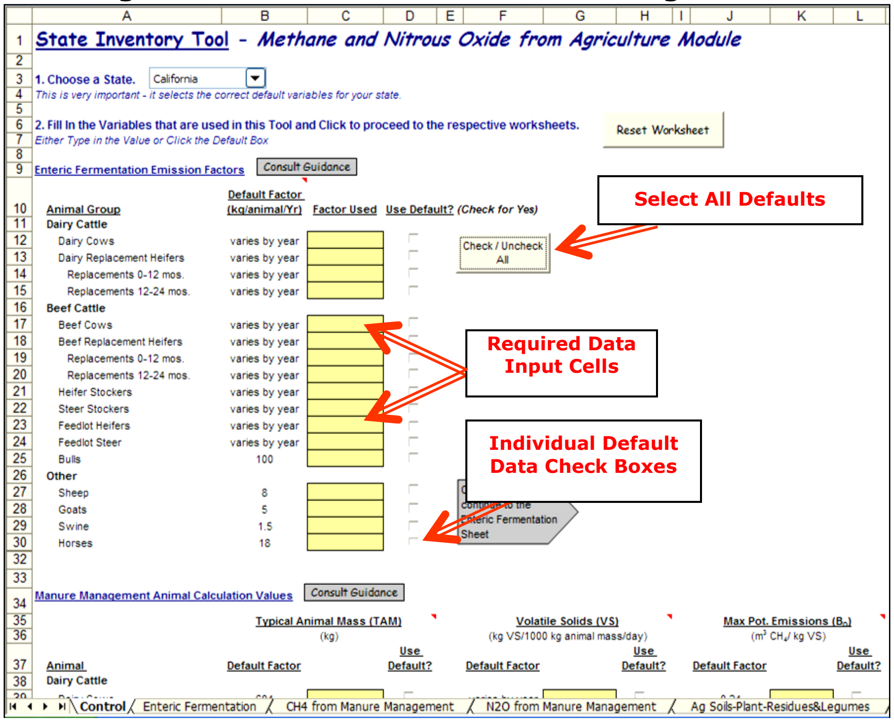
To begin, select the state you are interested in evaluating. By selecting a state, the rest of the tool will automatically reset to reflect the appropriate state default data and assumptions for use in subsequent steps of the tool.

Step (2) Enter Emission Factors and Activity Data for Enteric Fermentation

Control Worksheet

On the control worksheet, either select the default data provided or enter user-specified, animal or crop-specific data that will be used throughout the tool. To proceed with the default data, select the "Check/Uncheck All" button for each sector or check the individual default box directly to the right of specific yellow input cells. Note that this number can be overwritten if you later discover that the data for your state differ from the default data provided by the tool. To enter user-specified inputs, enter data directly into the yellow input cells. If the user-specific inputs do not match the default data in the control worksheet (i.e., the default value is overwritten), the text will appear red. See Figure 4 for locations of the "Check/Uncheck All" buttons, individual default check boxes, and yellow input cells. Information requirements on the control worksheet for each sector are discussed separately below.

Figure 4. Control Worksheet for the Ag Module

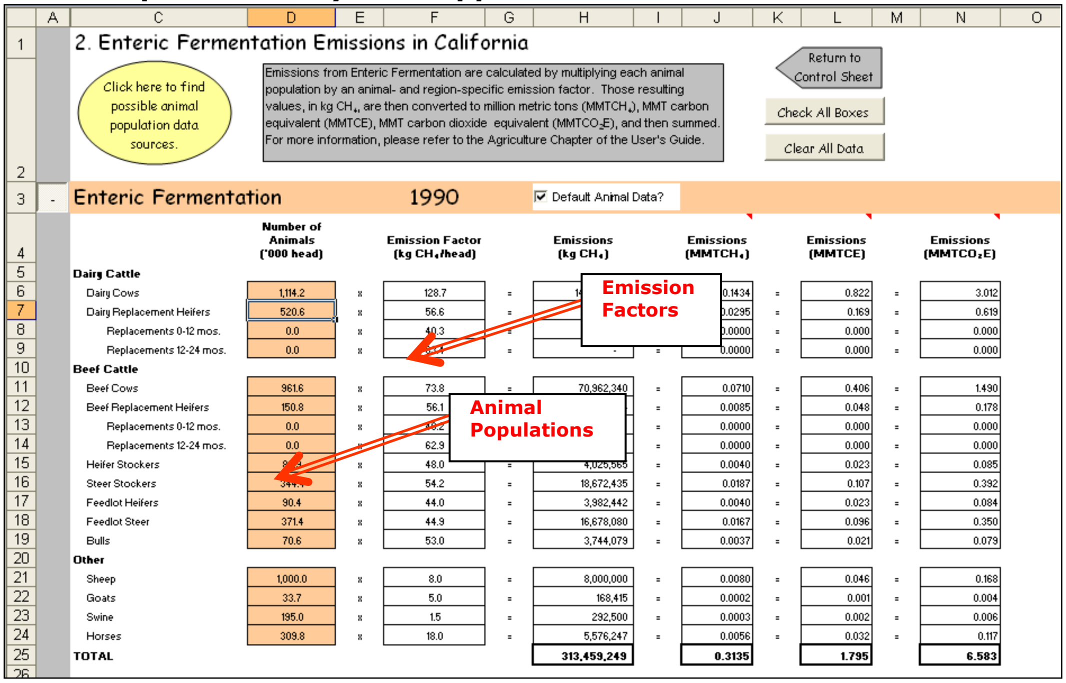


The first type of required data in the control worksheet is emission factors by animal type for enteric fermentation. CH_4 is produced as part of the normal digestive processes of animals. The amount of CH_4 produced by domesticated animals depends primarily on the type of animal (e.g., ruminant or non-ruminant), the age and weight of the animal, and the quantity and quality of the feed consumed (IPCC 2006). In general, ruminants produce more CH_4 than non-ruminants, and higher quality of feed produces lower emissions. The default emission factors for cattle are dependent on diet characteristics, such as digestible energy and CH_4 yield, which vary by diet and individual animal, and are provided on a regional basis from EPA (2024a). Default emission factors for other livestock types do not vary by animal production characteristics and are also from EPA (2024a). After completing the control worksheet for this sector, use the gray arrow to navigate to the sector worksheet.

Enteric Fermentation Sector Worksheet

The activity data required to populate the orange cells in the enteric fermentation worksheet are the average animal populations, over the course of the inventory year, for the following animals: cattle, sheep, goats, swine, and horses. The cattle population is separated into dairy and beef animals. Dairy animals are further disaggregated into cows and replacement heifers, while beef animals are disaggregated into bulls, cows, replacement heifers (for breeding stock), steer and heifer stockers (prior to moving into feedlots), and steer and heifer feedlot animals. An example of the data requirements used in the enteric fermentation sector worksheet is presented in Figure 5. Box 1 discusses additional notes if users plan on providing state-specific animal population data instead of using the default data.

Figure 5. Example of Activity Data Applied in the Enteric Fermentation Worksheet



2. Enteric Fermentation Emissions in California

Click here to find possible animal population data sources.

Emissions from Enteric Fermentation are calculated by multiplying each animal population by an animal- and region-specific emission factor. Those resulting values, in kg CH_4, are then converted to million metric tons ($MMTCH_4$), MMT carbon equivalent (MMTCE), MMT carbon dioxide equivalent ($MMTCO_2E$), and then summed. For more information, please refer to the Agriculture Chapter of the User's Guide.

Return to Control Sheet | Check All Boxes | Clear All Data

Enteric Fermentation 1990 ☑ Default Animal Data?

	Number of Animals ('000 head)		Emission Factor (kg CH_4/head)		Emissions (kg CH_4)		Emissions ($MMTCH_4$)		Emissions (MMTCE)		Emissions ($MMTCO_2E$)
Dairy Cattle											
Dairy Cows	1,114.2	x	128.7	=	[illegible]	=	0.1434	=	0.822	=	3.012
Dairy Replacement Heifers	520.6	x	56.6	=	[illegible]	=	0.0295	=	0.169	=	0.619
Replacements 0-12 mos.	0.0	x	40.3	=	[illegible]	=	0.0000	=	0.000	=	0.000
Replacements 12-24 mos.	0.0	x	[illegible]	=	-	=	0.0000	=	0.000	=	0.000
Beef Cattle											
Beef Cows	961.6	x	73.8	=	70,962,340	=	0.0710	=	0.406	=	1.490
Beef Replacement Heifers	150.8	x	56.1	=	[illegible]	=	0.0085	=	0.048	=	0.178
Replacements 0-12 mos.	0.0	x	[illegible]	=	[illegible]	=	0.0000	=	0.000	=	0.000
Replacements 12-24 mos.	0.0	x	62.9	=	[illegible]	=	0.0000	=	0.000	=	0.000
Heifer Stockers	[illegible]	x	48.0	=	4,025,565	=	0.0040	=	0.023	=	0.085
Steer Stockers	[illegible]	x	54.2	=	18,672,435	=	0.0187	=	0.107	=	0.392
Feedlot Heifers	90.4	x	44.0	=	3,982,442	=	0.0040	=	0.023	=	0.084
Feedlot Steer	371.4	x	44.9	=	16,678,080	=	0.0167	=	0.096	=	0.350
Bulls	70.6	x	53.0	=	3,744,079	=	0.0037	=	0.021	=	0.079
Other											
Sheep	1,000.0	x	8.0	=	8,000,000	=	0.0080	=	0.046	=	0.168
Goats	33.7	x	5.0	=	168,415	=	0.0002	=	0.001	=	0.004
Swine	195.0	x	1.5	=	292,500	=	0.0003	=	0.002	=	0.006
Horses	309.8	x	18.0	=	5,576,247	=	0.0056	=	0.032	=	0.117
TOTAL					**313,459,249**		**0.3135**		**1.795**		**6.583**

Box 1: Caution When Providing Animal Population Data

If you decide to use animal population data that is different from the default data, please be aware of the following possible data issues:

Animal populations fluctuate during the year, in some cases by large amounts. For example, a census done before calving will give a much smaller number than a census done after calving. Thus, the average animal population over the course of the inventory year should be used in the estimates (termed here the "annual average population"). For some animals, a specific state's population may only be given for one month, while the national population is given at other points during the year. In this case a state's annual average animal population may be estimated based on the animal population in the state in a given month, and an adjustment factor developed with (2) the national population of the animal in the same month, and (2) the national population of the animal either six months before or after. Therefore, to obtain an average annual animal population it may be necessary to use animal census data from multiple points throughout each year.

Note that for enteric fermentation the tool gives users the option of providing heifer replacement data in aggregate or by age class (0 – 12 months and 12 – 24 months); default populations are provided in aggregate although default emission factors are provided for both options. If users provide data by age class, it is important to make sure that the total heifer replacement data are deleted to avoid double counting.

Finally, emissions estimates for enteric fermentation and manure management rely on the same underlying livestock population data and livestock characteristic data. Therefore, if not using default data it is important to use the same population data to estimate emissions from these two source categories. Note that although the specific sub-categories of livestock types may vary between the two sources, they should rely on the same underlying population data. For example, total swine populations are used for enteric fermentation, while swine are split into breeding and market, and further divided by weight class in the manure management source category. Additionally, calves are omitted in the enteric fermentation estimates; this is because emissions are assumed to be zero through six months of age. Emissions from calves are included in the manure management estimates; therefore, the calf populations are required in that worksheet.

The Ag module calculates emissions for enteric fermentation by multiplying animal populations by the annual emission factor to obtain the total CH_4 emitted. Then, the total CH_4 emitted is converted into carbon dioxide (CO_2) equivalents by multiplying by the GWP of CH_4 (28). Finally, emissions are divided by 10^9 to express emissions in $MMTCO_2E$. Equation 1 demonstrates the emission calculation for enteric fermentation.

Equation 1. Emission Equation for Enteric Fermentation

Emissions ($MMTCO_2E$) =
Animal Population ('000 head) × Emission Factor (kg CH_4/head) × 28 (GWP)
÷ 1,000,000,000 (kg/$MMTCO_2E$)

Once this sector worksheet is complete, use the gray navigational arrow to return to the control worksheet and proceed to the next sector.

Step (3) Enter Emission Factors and Activity Data for Manure Management

Emissions from animal waste during storage in a management system are accounted for in this sector. Following storage in a management system it is then assumed that the manure is ultimately applied to soils, where further emissions take place. These subsequent emissions, as well as a third emission type, manure managed through daily spread, are considered to be emissions from agricultural soils, and are discussed in Step 4.

Control Worksheet

Both CH_4 and N_2O are produced during the manure decomposition process. The data required for manure management sector within the control worksheet are the typical animal mass (TAM), volatile solids (VS) production, and maximum CH_4 producing capacity (B_o), which are pulled into manure CH_4 worksheet. Each data requirement is discussed in more detail below:

- Typical animal mass is the average mass of the entire animal population sub-category, expressed in kg.

- Volatile solids are defined as the organic fraction of the total solids in manure that will oxidize and be driven off as gas at a temperature of 1,112°F. Total solids are defined as the material that remains after evaporation of water at a temperature between 217° and 221°F. CH_4 emissions from livestock are directly related to the amount of VS produced. Production of VS is reported in the tool as kg VS per head per year for cattle (excluding calves), and as kg VS per 1,000 kg of animal mass per day for calves and all other livestock (i.e., swine, poultry, sheep, goats, and horses).

- The CH_4-producing capacity of livestock manure is generally expressed in terms of the quantity of CH_4 that can be produced per kilogram of VS in the manure. This quantity is determined by animal type and diet and is commonly referred to as B_o with units of cubic meters of CH_4 per kilogram VS (m^3 CH_4/kg VS).

After completing the control worksheet for this sector, use the gray arrows to navigate to the sector worksheets.

Step (3a) CH_4 from Manure Management Sector Worksheet

To estimate CH_4 emissions from manure, information is input into the blue cells in Figure 6 on annual average animal populations (in number of head) for the following animal types: cattle (by type), swine (by type), poultry (by type), sheep (by type), goats, and horses. The red arrows in Figure 6 indicate the areas where the required data are entered or pulled through to the manure management worksheet from the control worksheet. If users plan on providing their own animal population data, please review the notes in Box 1. When decomposition occurs without oxygen (i.e., anaerobic decomposition) CH_4 is produced. The CH_4-producing capacity of livestock manure depends on the specific composition of the manure, which in turn depends on the composition and digestibility of the animal diet. In general, the greater the energy content of the feed, the greater the CH_4-producing capacity of the resulting manure.

The Ag module calculates CH_4 emissions for manure management by first calculating total VS produced by the state's livestock. To do so, each animal type population is multiplied by the VS production rate, provided in kg/head/year for cattle (excluding calves), and kg/1,000 kg animal mass/day for calves and all other livestock (i.e., swine, poultry, sheep, goats, and horses). For cattle (excluding calves), animal population is multiplied by the VS rate (kg/head/year) for total VS produced. For calves and all other livestock, animal population is multiplied by the TAM (kg), VS rate (kg/1,000 kg animal mass/day), and number of days per year to obtain the total annual VS produced.

This value is multiplied by B_o, and the weighted CH_4 conversion factor (MCF),[1] resulting in m^3 CH_4. The total m^3 CH_4 emitted is converted into CO_2 equivalents by multiplying by density of CH_4 (0.678 kg/m^3 CH_4) the GWP of CH_4 (28). Finally, emissions are divided by 10^9 to express emissions in $MMTCO_2E$. Equation 2 demonstrates the calculation CH_4 emissions for manure management.

Equation 2. Emission Equation for CH_4 Manure Management

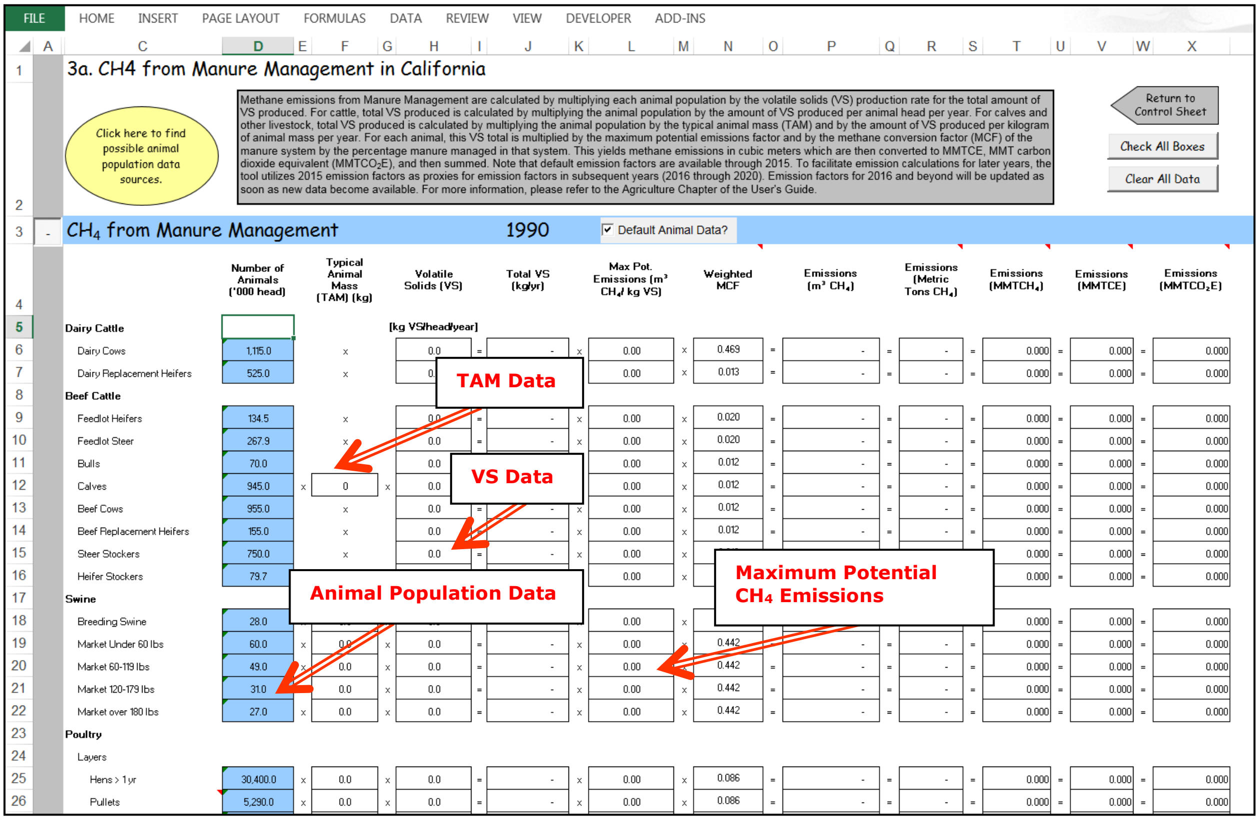
VS Produced$_{\text{Cattle, excluding calves}}$ = Animal Population ('000 head) × 1,000 × VS (kg/head/yr)

VS Produced$_{\text{Calves and all other livestock}}$ = Animal Population ('000 head) × TAM × VS (kg/1,000 kg animal mass/day) × 365 (days/yr)

Emissions ($MMTCO_2E$) =
VS Produced (kg) × B_o (m^3 CH_4/kg VS) × MCF × 0.678 kg/m^3 × 28 (GWP) ÷ 1,000,000,000 ($MMTCO_2E$)

[1] MCF represents the extent to which the B_o is realized for a given livestock manure management system environmental conditions. The weighted MCF for each animal type is based on default data for the percent of each animal type's manure handled in manure management systems and the MCF for each system.

Figure 6. Example of Activity Data Applied in the Manure Management CH_4 Worksheet



Step (3b) N_2O from Manure Management Sector Worksheet

Once the K-Nitrogen is entered onto the control worksheet under the agricultural soils step and the animal population data are entered into the manure management CH_4 worksheet, no additional data are required to produce emission estimates of N_2O from manure management. Figure 7 shows an example of the worksheet for N_2O from manure management.

Production of N_2O during the storage and treatment of animal wastes occurs by combined nitrification-denitrification of nitrogen contained in ammonia that is present in the wastes. In order for N_2O to be produced, the manure must first be in an aerobic system, in which the nitrogen in ammonia is converted to nitrites (nitrification). Following this the manure must go through an anaerobic decomposition period, in which the nitrates are converted to N_2O (denitrification). These types of conditions are most likely to occur in dry manure management systems that generally have aerobic conditions, but that can undergo periods of saturation to create the anaerobic conditions necessary for N_2O emissions to occur. The amount of N_2O released depends on the system and the duration of waste management.

To estimate N_2O emissions from manure management, the Ag module first calculates the total K-nitrogen excreted by the state's livestock. To do so, each animal type population is multiplied by the K-nitrogen excretion rate, provided in kg/head/year for cattle (excluding calves), and kg/1,000 kg animal mass/day for calves and all other livestock (i.e., swine, poultry, sheep, goats, and horses). For cattle (excluding calves), animal population is multiplied by the K-nitrogen excretion rate (kg/head/year) for total K-nitrogen excreted. For calves and all other livestock, animal population is multiplied by the TAM (kg), the K-nitrogen excretion rate (kg/1,000 kg animal mass/day), and 365 days per year for total K-nitrogen excreted.

Next the tool separates the total K-nitrogen into the amount in liquid systems (lagoons and liquid/slurry) and dry systems (drylot and solid storage), and multiplies by the emission factor specific to these types of systems (0.001 kg N20-N/kg N for liquid systems and 0.2 kg N20-N/kg N for dry systems). Finally, total kg N_2O emissions are converted to $MMTCO_2E$ by multiplying by the GWP of N_2O (265) and dividing by 10^9 to convert from kg to $MMTCO_2E$. Equation 3 demonstrates the calculation N_2O emissions for manure management.

Equation 3. Emission Equation for N_2O Manure Management

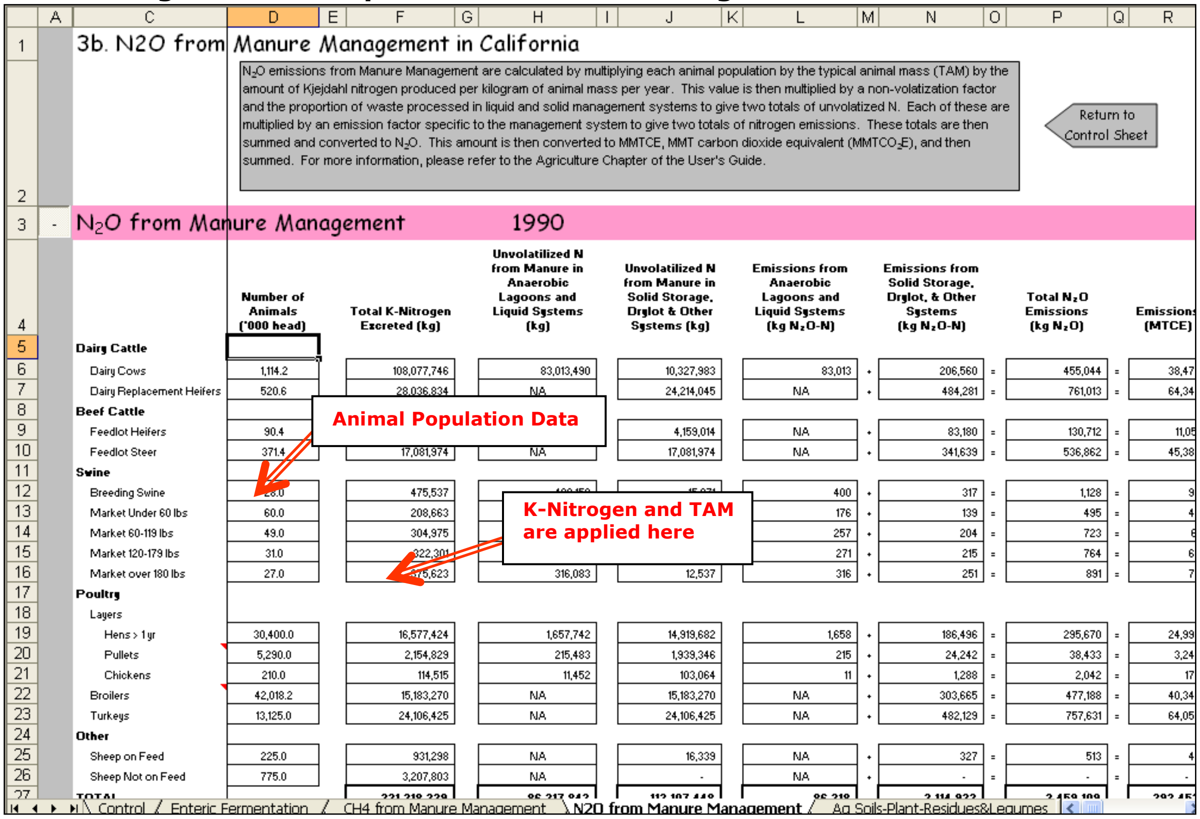
K-Nitrogen Excreted$_{\text{Cattle, excluding calves}}$ = Animal Population (‘000 head) × 1,000 × K-Nitrogen (kg/head/day)

K-Nitrogen Excreted$_{\text{Calves and all other livestock}}$ = Animal Population (‘000 head) × TAM × K-Nitrogen (kg/1,000 kg animal mass/day) × 365 (days/yr)

Emissions ($MMTCO_2E$) =
K-Nitrogen Excreted × Emission Factor (liquid or dry) ×
265 (GWP) ÷ 1,000,000,000 (kg/$MMTCO_2E$)

Once this sector worksheet is complete, use the gray navigational arrow to return to the control worksheet and proceed to the next sector.

Figure 7. Example of the Manure Management N_2O Worksheet



	Number of Animals ('000 head)	Total K-Nitrogen Excreted (kg)	Unvolatilized N from Manure in Anaerobic Lagoons and Liquid Systems (kg)	Unvolatilized N from Manure in Solid Storage, Drylot & Other Systems (kg)	Emissions from Anaerobic Lagoons and Liquid Systems (kg N_2O-N)		Emissions from Solid Storage, Drylot, & Other Systems (kg N_2O-N)		Total N_2O Emissions (kg N_2O)		Emissions (MTCE)
Dairy Cattle											
Dairy Cows	1,114.2	108,077,746	83,013,490	10,327,983	83,013	+	206,560	=	455,044	=	38,47
Dairy Replacement Heifers	520.6	28,036,834	NA	24,214,045	NA	+	484,281	=	761,013	=	64,34
Beef Cattle											
Feedlot Heifers	90.4	[illegible]	[illegible]	4,159,014	NA	+	83,180	=	130,712	=	11,05
Feedlot Steer	371.4	17,081,974	NA	17,081,974	NA	+	341,639	=	536,862	=	45,38
Swine											
Breeding Swine	[illegible]	475,537	[illegible]	[illegible]	400	+	317	=	1,128	=	9
Market Under 60 lbs	60.0	208,663	[illegible]	[illegible]	176	+	139	=	495	=	4
Market 60-119 lbs	49.0	304,975	[illegible]	[illegible]	257	+	204	=	723	=	6
Market 120-179 lbs	31.0	322,301	[illegible]	[illegible]	271	+	215	=	764	=	6
Market over 180 lbs	27.0	[illegible]	316,083	12,537	316	+	251	=	891	=	7
Poultry											
Layers											
Hens > 1 yr	30,400.0	16,577,424	1,657,742	14,919,682	1,658	+	186,496	=	295,670	=	24,99
Pullets	5,290.0	2,154,829	215,483	1,939,346	215	+	24,242	=	38,433	=	3,24
Chickens	210.0	114,515	11,452	103,064	11	+	1,288	=	2,042	=	17
Broilers	42,018.2	15,183,270	NA	15,183,270	NA	+	303,665	=	477,188	=	40,34
Turkeys	13,125.0	24,106,425	NA	24,106,425	NA	+	482,129	=	757,631	=	64,05
Other											
Sheep on Feed	225.0	931,298	NA	16,339	NA	+	327	=	513	=	4
Sheep Not on Feed	775.0	3,207,803	NA	-	NA	+	-	=	-	=	-
TOTAL		[illegible]	[illegible]	[illegible]	[illegible]		[illegible]		[illegible]		[illegible]

Step (4) Enter Emission Factors and Activity Data for Agricultural Soils

Emissions from agricultural soils are divided into three worksheets in the SIT, 1) residues, legumes, and histosols; 2) fertilizers; and 3) animals. In addition, emissions can be either direct through cropping and animal management practices or indirect through either volatilization into the atmosphere as NO_x and NH_3 or from agricultural leaching and runoff. Both direct and indirect emissions are estimated in the worksheets described below.

Control Worksheet

N_2O is produced naturally in soils through the microbial processes of denitrification and nitrification.[2] A number of anthropogenic activities add nitrogen to soils, thereby increasing the amount of nitrogen available for nitrification and denitrification, and ultimately the amount of N_2O emitted. These activities include application of fertilizers, animal production, cultivation of nitrogen-fixing crops, incorporation of crop residues, and cultivation of histosols (highly organic soils). The sources of N_2O described here are divided into three categories: (1) direct emissions from agricultural soils due to cropping practices; (2) direct and indirect emissions from soils from fertilizer application; and (3) direct and indirect emissions from agricultural soils due to animal production. Each of these is discussed in more detail in Step 4. Within the control worksheet data must be entered by crop type for

---

[2] Denitrification, the process by which nitrates or nitrites are reduced by bacteria, results in the release of nitrogen into the air. Nitrification is the process by which bacteria and other microorganisms oxidize ammonium salts to nitrites, and further oxidize nitrites to nitrates.

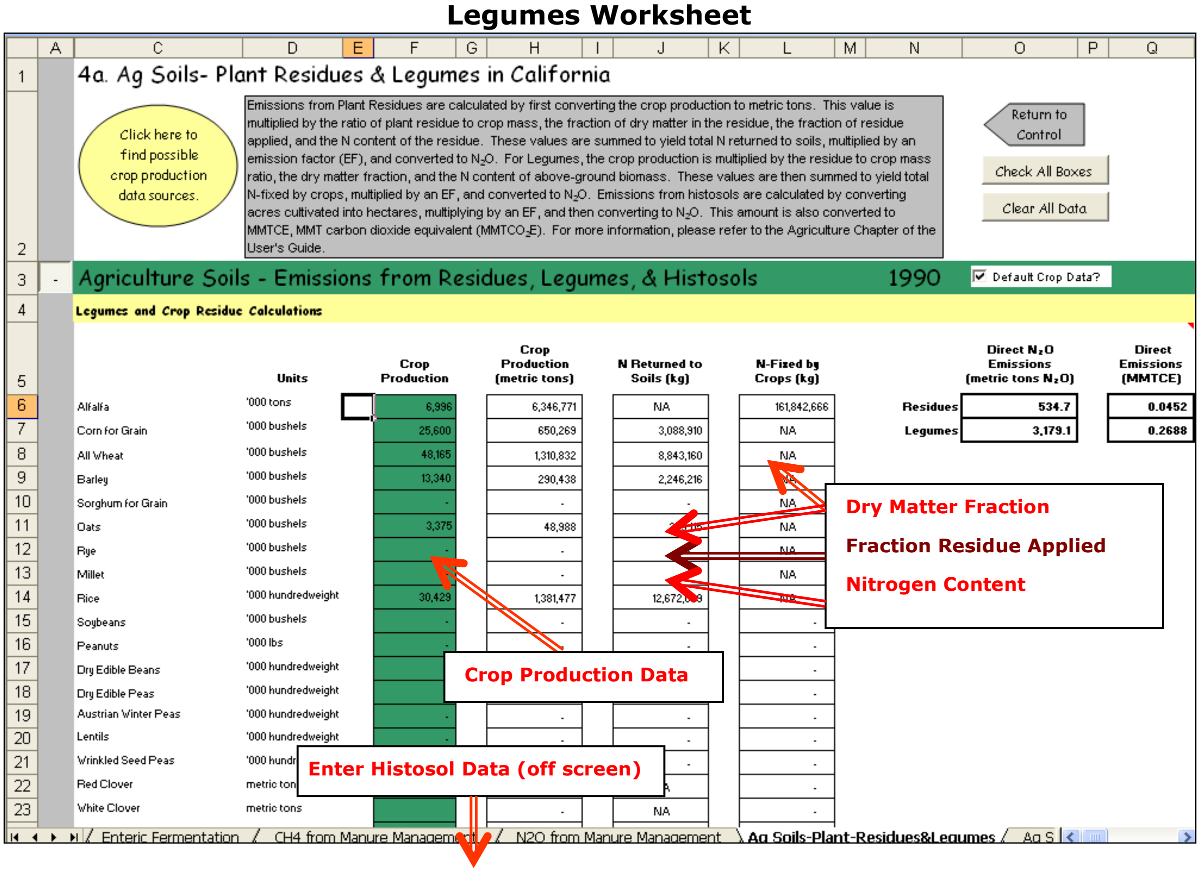
residue dry matter fraction, fraction residue applied, and nitrogen (N) content of residue. Crop types utilized include alfalfa, corn for grain, all wheat, barley, sorghum, oats, rye, millet, rice, soybeans, peanuts, dry edible beans, dry edible peas, austrian winter peas, lentils, and wrinkled seed peas. Additionally, K-nitrogen is entered by animal type for dairy and beef cattle (by type), swine (by type), poultry (by type), sheep, goats, and horses.

Data on the residue dry matter fraction, fraction residue applied, and N content of residue are pulled into the agricultural soils emissions from residues, legumes, and histosols worksheet. K-nitrogen is pulled into the agricultural soils-animals worksheet along with animal population data and TAM from the manure management sector. After completing the control worksheet for this sector, use the gray arrows to navigate to the sector worksheets.

Step (4a) N_2O from Agricultural Soils Sector Worksheet – Residues, Legumes, and Histosols

This worksheet covers N_2O emitted from agricultural soils due to biological nitrogen fixation by certain crops, crop residues remaining on agricultural fields, and histosol cultivation. Figure 8 presents an example of the data, as used in the calculations on this worksheet.

Figure 8. Example of Activity Data Applied in the Agricultural Soils Residues and Legumes Worksheet



N_2O is emitted from the cultivation of N-fixing crops, also known as legumes. To estimate state emissions of N_2O from N-fixing crops, data on the amount of beans (by type), pulses (by type), and alfalfa produced in the state is input into the dark green cells in Figure 8. In addition, data on production of non-alfalfa forage crops, such as red clover, white clover, birdsfoot trefoil, arrowleaf clover, and crimson clover are desirable. In order to calculate the total N input from N-fixing crops, the SIT multiplies the production of each type of N fixing crop by the residue to crop mass ratio for each crop, the residue dry matter fraction, and the nitrogen content in each crop. For forage crops total N input is simply calculated as the production of N-fixing forage crops multiplied by the nitrogen content of the crop. The total N input for all N-fixing crops is multiplied by the emission factor for direct emissions of N_2O (1.0 percent) to obtain the amount of emissions in N_2O-N/yr. The result is converted from kg N_2O-N to $MMTCO_2E$ by multiplying the emissions from crop residues by 44/28 (the molecular weight ratio of N_2O/N_2O-N) and by the GWP of N_2O (265) and dividing by 10^6 to convert from metric tons to $MMTCO_2E$. Equation 4 shows emission calculations from N-fixing crops.

Equation 4. Emission Equation for N-fixing Crops

Emissions ($MMTCO_2E$) =
Crop Production (MT) × Mass ratio (residue/crop) × Dry Matter Fraction × N content × Emission Factor (1.0%) × 44/28 (Ratio of N_2O to N_2O-N) × 265 (GWP) ÷ 1,000,000 (MT/$MMTCO_2E$)

N_2O is also emitted from crop residue that is incorporated into the soil (i.e., the portion of the crop that has been neither removed from the field as crop nor burned). To estimate the total N in crop residues returned to the soil for each crop, the SIT multiplies the production of each crop by the crop residue to crop mass ratio, the dry matter fraction for residue, the fraction of residue applied (accounting for removal of crop and the fraction burned), and the N content of the residue. Next, the total N in all crop residues is multiplied by the emission factor for direct emissions of N_2O (1.0 percent) to obtain the amount of emissions in N_2O-N/yr. The result is converted from kg N_2O-N to $MMTCO_2E$ by multiplying the amount of emissions from crop residues by 44/28 (the molecular weight ratio of N_2O/N_2O-N) and by the GWP of N_2O (265) and dividing by 10^9 to convert from kg to $MMTCO_2E$. Equation 5 shows emission calculations from N-fixing crops.

Equation 5. Emission Equation for Residues

Emissions ($MMTCO_2E$) =
Crop Production (MT) × Mass ratio (residue/crop) × Dry Matter Fraction × Fraction Residue Applied × N content × Emission Factor (1.0%) × 44/28 (Ratio of N_2O to N_2O-N) × 265 (GWP) ÷ 1,000,000,000 (kg/$MMTCO_2E$)

N_2O is also emitted from the cultivation of high organic content soils, or histosols. To estimate state emissions of N_2O from the cultivation of histosols, the SIT requires data on histosol cultivation acreage by temperate and sub-tropical climate types. To calculate the direct emissions from histosols, the acreage of cultivated soils is converted into hectares and multiplied by the appropriate emission factor for the climate type (8 for temperate or 12 for sub-tropical) in kg N_2O-N per hectare per year. The result is converted from kg N_2O-N to $MMTCO_2E$ by multiplying the emissions by 44/28 (the molecular weight ratio of N_2O/N_2O-N) and by the GWP of N_2O (265) and dividing by 10^9 to convert from kg to $MMTCO_2E$. Equation 6 shows emission calculations from N-fixing crops.

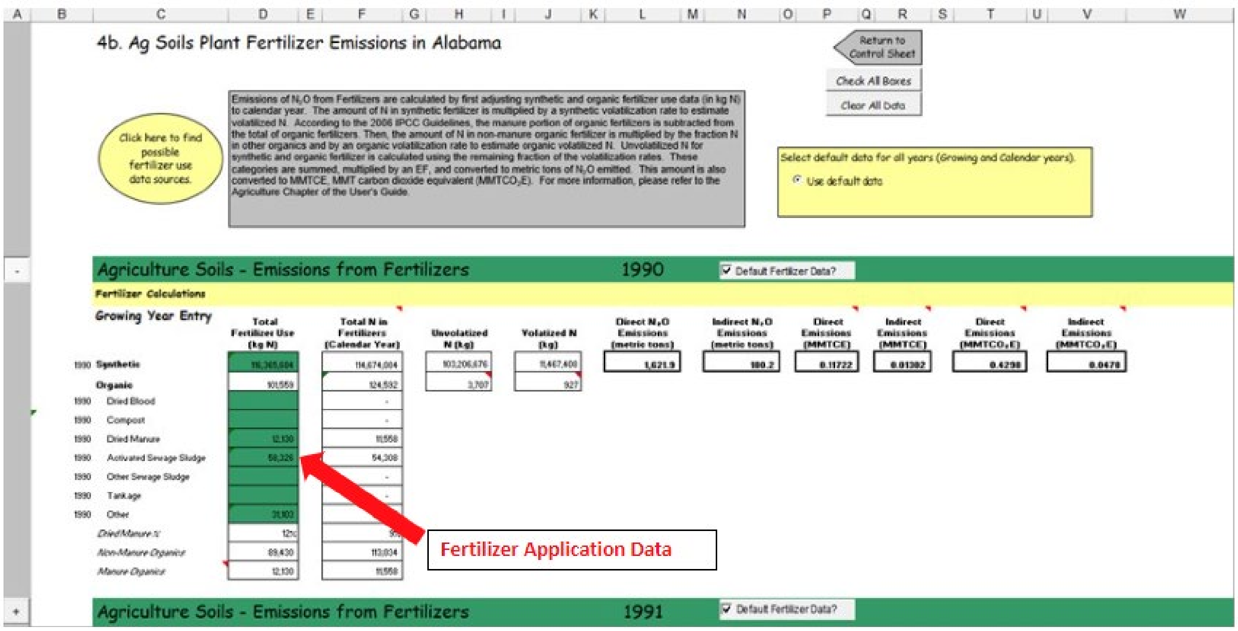
Equation 6. Emission Equation for Histosols

Emissions ($MMTCO_2E$) =
Area Cultivated (acres) × 1/2.471 (ha/ac) × Emission Factor (kg N_2O-N/ha/yr) × 44/28 (Ratio of N_2O to N_2O-N) × 265 (GWP) ÷ 1,000,000,000 (kg/$MMTCO_2E$)

Step (4b) N_2O from Agricultural Soils Sector Worksheet – Fertilizers

This worksheet estimates both direct and indirect emissions from agricultural soils due to synthetic fertilizer use and organic fertilizer use, including dried blood, compost, tankage, and land application of sewage sludge[3], as shown in Figure 9.

Figure 9. Example of Required Data in the Agricultural Soils Fertilizers Worksheet



To complete this worksheet fertilizer deposition data are required in the dark green cells in Figure 9 for the growing season year, with defaults provided for a standard calendar year in the second column. If fertilizer use data are entered on a growing year basis, the first step of the calculation is to convert it to calendar years by taking 65 percent of fertilizer use from the year being calculated and the remaining 35 percent from use the subsequent year.

Emission calculations begin by multiplying total non-manure organic fertilizer use by the percent of N in organic fertilizer to calculate total N present. Next volatilized and unvolatilized N are disaggregated to separate calculations for direct emissions from fertilizer application and indirect emissions through volatilization as ammonia (NH_3) and nitrogen oxides (NO_x). The fraction of volatilized N is assumed to be 10 percent of synthetic fertilizer and 20 percent of organic fertilizer. Thus, direct emissions are calculated by multiplying total N by 0.9 for synthetic fertilizer and 0.8 for organic fertilizer to obtain the amount of unvolatilized N. This value is multiplied by the emission factor for direct emissions of N_2O (1.0 percent) to obtain the amount of emissions in N_2O-N/yr and converted from kg N_2O-N to kg N_2O by multiplying by the ratio of N_2O/N_2O-N (44/28). Indirect emissions are calculated by multiplying the total fertilizer N that volatilizes by the volatilization emission factor (0.001 kg N_2O-N/kg N) and converting from kg N_2O-N to kg N_2O by multiplying by the

---

[3] In accordance with the IPCC Good Practice Guidelines, manure used as commercial fertilizer is subtracted from total organic fertilizer use to avoid double-counting with the Agricultural Soils from Animals.

ratio of N_2O/N_2O-N (44/28). Note that indirect emissions from leaching are accounted for in the agricultural soils-animals worksheet, which is discussed below in Step 3c.

Finally, both direct and indirect emissions are converted from kg N_2O to $MMTCO_2E$ by multiplying by the GWP of N_2O (265) and dividing by 10^9 to convert from kg to $MMTCO_2E$. Equation 7 demonstrates the calculation for direct emissions and indirect emissions are shown in Equation 8.

Equation 7. Emission Equation for Direct N_2O Emissions from Agricultural Soils

$$\begin{gathered}\textbf{Emissions } (MMTCO_2E) = \\ \textbf{Total N} \times \textbf{fraction unvolatilized (0.9 synthetic or 0.8 organic)} \\ \times\ \textbf{0.01 (kg } N_2O\textbf{-N/kg N)} \times \textbf{44/28 (Ratio of } N_2O \textbf{ to } N_2O\textbf{-N)} \times \textbf{265 (GWP)} \\ \div\ \textbf{1,000,000,000 (kg/}MMTCO_2E\textbf{)}\end{gathered}$$

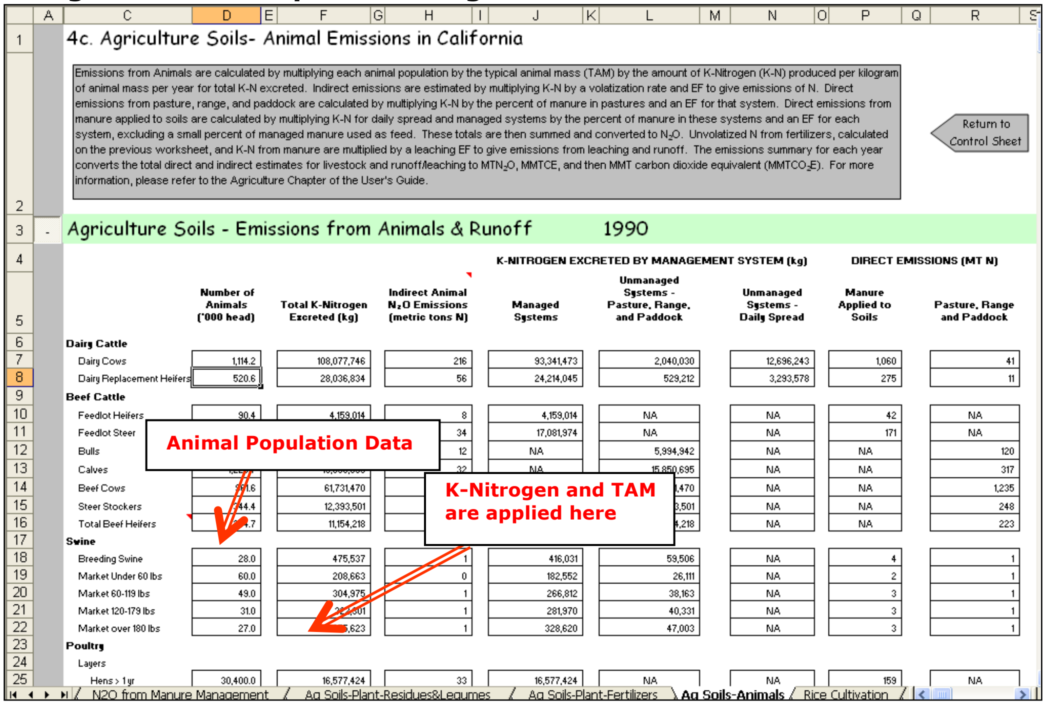
Equation 8. Emission Equation for Indirect N_2O Emissions from Agricultural Soils

$$\begin{gathered}\textbf{Emissions } (MMTCO_2E) = \\ \textbf{Total N} \times \textbf{fraction volatilized (0.1 synthetic or 0.2 organic)} \\ \times\ \textbf{0.001 (kg } N_2O\textbf{-N/kg N)} \times \textbf{44/28 (Ratio of } N_2O \textbf{ to } N_2O\textbf{-N)} \times \textbf{265 (GWP)} \\ \div\ \textbf{1,000,000,000 (kg/}MMTCO_2E\textbf{)}\end{gathered}$$

Step (4c) N_2O from Agricultural Soils Sector Worksheet – Animals

To calculate N_2O emissions for this worksheet, no additional data are required. Figure 10 shows an example of the agricultural soils-animals worksheet. Nitrogen flux from animal production is dependent on the waste management system employed (if any) and the amount of waste excreted. The methodology presented in this section does not account for site-specific conditions that could affect either the amount of nitrogen excreted or the resulting emission factor for N_2O emissions. These conditions could include temperature, humidity, and others. Estimates include direct emissions from application of animal waste through daily spread operations, eventual application of managed animal wastes, and animal wastes that are deposited directly on soils by animals in pastures, ranges, and paddocks. In addition, indirect emissions from volatilization, leaching, and run-off are also estimated. This method reflects the assumption that all manure is eventually applied to agricultural soils as a mode of disposal.

Figure 10. Example of the Agricultural Soils Animals Worksheet



The SIT calculates emissions by multiplying each animal population (entered in the manure management worksheet) by the rate of N excreted by animal type, provided in kg/head/year for cattle (excluding calves), and kg/1,000 kg animal mass/day for calves and all other livestock (i.e., swine, poultry, sheep, goats, and horses). For cattle (excluding calves), animal population is multiplied by the K-nitrogen excretion rate (kg/head/year) for total K-nitrogen excreted. For calves and all other livestock, animal population is multiplied by the TAM (kg), the K-nitrogen excretion rate (kg/1,000 kg animal mass/day), and 365 days per year for total K-nitrogen excreted. Next, the total K-nitrogen is disaggregated into manure handled in managed systems, manure applied as daily spread, and manure deposited directly into pastures, ranges, or paddocks, based on default percentages obtained from the U.S. Inventory (EPA 2024a).

Direct emissions from manure handled in management systems and applied as daily spread is multiplied by the volatilization factor (0.8) to obtain the total unvolatilized N. Additionally, for poultry an adjustment must be made for the small portion of waste used as animal feed. For all poultry categories (i.e., layers (hens, pullets, and chickens), broilers, and turkeys), the total K-nitrogen in managed systems is multiplied by 0.958, as it is assumed that 4.2 percent of all poultry manure is used as animal feed and not applied to agricultural soils (Carpenter 1992). The total unvolatilized N is multiplied by the emission factor for direct emissions of N_2O (1.0 percent) to obtain the amount of emissions in N_2O-N/yr.

For animal waste deposited directly onto pasture, range, and paddock the total K-nitrogen is multiplied by the percent of manure deposited on pasture, range, and paddocks and the IPCC default emission factor for direct emissions (0.02 kg N_2O-N/kg N excreted) (IPCC 1997, 2024a) to obtain the amount of emissions in N_2O-N/yr.

Indirect emissions from volatilization to NH_3 and NO_x are estimated as 20 percent of the total K-nitrogen excreted per year multiplied by the emission factor of 0.001 kg N_2O-N/kg N, following the methodology of organic fertilizers, shown in Equation 8.

Indirect emissions from leaching and runoff are assumed to occur from 30 percent of the total unvolatilized N. Therefore, indirect emissions from leaching and runoff are calculated by multiplying the total unvolatilized N by 0.30 and the emission factor (0.0075 kg N_2O-N/kg N). The result is converted to $MMTCO_2E$ using the methodology described below.

Finally, both direct and indirect emissions are converted from kg N_2O-N to $MMTCO_2E$ by multiplying emissions by the molecular weight ratio of N_2O/N_2O-N (44/28) and by the GWP of N_2O (265) and dividing by 10^9 to convert from kg to $MMTCO_2E$. Equation 7 shows the general equation for the calculation for direct emissions (adjustment for poultry is not shown) and indirect emissions are shown in Equation 8. Once this sector worksheet is complete, use the gray navigational arrow to return to the control worksheet and proceed to the next sector.

Step (5) Enter Emission Factors and Activity Data for Rice Cultivation

Control Worksheet

For the rice cultivation sector, seasonal emission factors are required in the control worksheet. Mean seasonal emission factors are used to calculate CH_4 emissions from the primary and ratoon[4] crops. Rice fields for the ratoon crop typically remain flooded for a shorter period of time than for the first crop. Studies indicate, however, that the CH_4 emission rate of the ratoon crop may be significantly higher than that of the primary crop. The rice straw produced during the first harvest has been shown to dramatically increase CH_4 emissions during the ratoon cropping season (Lindau & Bollich, 1993). The higher emission rate of the ratoon crop supports the use of separate emission factors for the primary and ratoon rice crops. Seasonal emission factors for rice cultivation are pulled into the sector worksheet. After completing the control worksheet for this sector, use the gray arrow to navigate to the sector worksheet.

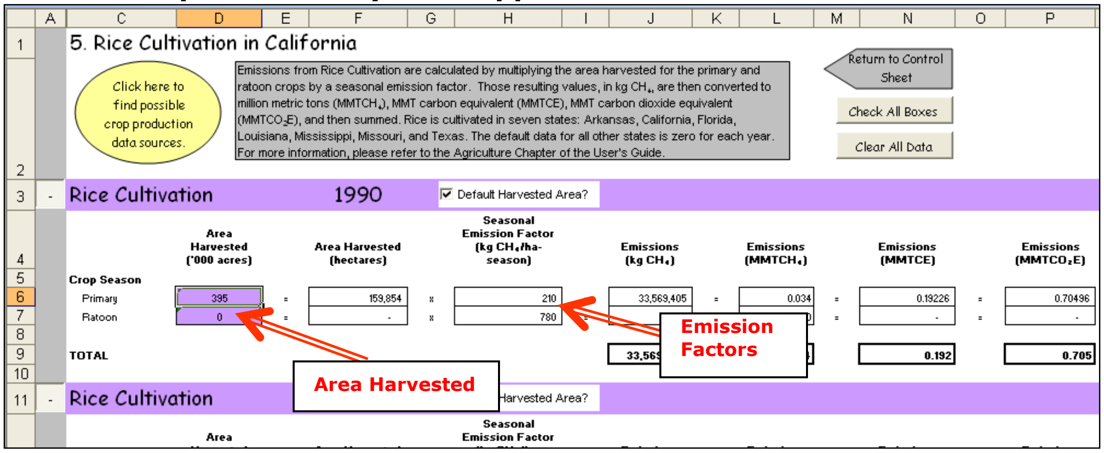
Rice Cultivation Sector Worksheet

The rice cultivation worksheet in the Ag Module requires data input in the purple cells on the total acreage of rice grown during both the primary and the ratoon growing seasons.

Figure 11 demonstrates where the acreage data and emission factors are used in the rice cultivation worksheet.

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

Figure 11. Example of Activity Data Applied in the Rice Cultivation Worksheet



Most of the world's rice, and all of the rice in the United States[5], is grown on flooded fields. When fields are flooded, aerobic decomposition of organic material gradually depletes the oxygen present in the soils and floodwater, and anaerobic conditions develop in the soils. At that point, CH_4 is produced through anaerobic decomposition of organic matter by methanogenic bacteria. However, not all of the CH_4 that is produced is released into the atmosphere. As much as 60 to 80 percent of the CH_4 produced is oxidized by aerobic methanotrophic bacteria in the soils (Holzapfel-Pschorn et al. 1985, Sass et al. 1990). Some of the CH_4 is also leached to ground water as dissolved CH_4. The remaining non-oxidized CH_4 is transported from the soil to the atmosphere primarily by diffusive transport through the rice plants. Additional CH_4 can escape from the soil via diffusion and bubbling through the floodwaters.

Other factors that influence CH_4 emissions from flooded rice fields include soil temperature, soil type, fertilization practices, rice cultivar selection, and other cultivation practices (e.g., tillage, seeding, and weeding practices). However, while it is generally acknowledged that these factors influence CH_4 emissions, the extent of the influence of these factors individually or in combination has not been well quantified. Thus, the method for estimating emissions is based on a range of measured emissions per unit area of flooded rice field per season.

CH_4 emissions from rice cultivation are calculated based on the acreage of rice grown (i.e., flooded) multiplied by emission factors for the amount of CH_4 emitted per flooding season. The results are converted to $MMTCO_2E$ by multiplying by the GWP of CH_4 (28) and the ratio of C to CO_2 (12/44) and dividing by 10^9 to convert from kg to million metric tons, as shown in Equation 9.

Equation 9. Emission Equation for Rice Cultivation

Emissions (($MMTCO_2E$) =
Area Harvested ('000 acres) × 1/2.471 (ha/acre) × Emission Factor (kg CH_4/ha-season) × 28 (GWP) ÷ 1,000,000,000 (kg/($MMTCO_2E$)

5 Eight states have grown or currently grow rice: Arkansas, California, Florida, Louisiana, Mississippi, Missouri, Oklahoma, and Texas.

Once this sector worksheet is complete, use the gray navigational arrow to return to the control worksheet and proceed to the next sector.

Step (6) Enter Emission Factors and Activity Data for Liming of Soils

Control Worksheet

The data entered in the control worksheet for this sector are emission factors for limestone and dolomite used in liming of soils. These emission factors should be in metric tons of carbon per metric ton of limestone (or dolomite). The default values are based on West & McBride (2005); if emission factors other than module defaults are available for limestone and dolomite, you should document their source carefully. If the user-specific inputs do not match the default data in the control worksheet (i.e., the default value is overwritten), the text will appear red.

Limestone ($CaCO_3$) and dolomite ($CaMg(CO_3)_2$) are added to soils by land managers to remedy acidification. When these compounds come in contact with acidic soils, they degrade, thereby generating CO_2. This section presents the methodology for calculating the CO_2 emissions from the application of limestone and dolomite to soils.

After entering the appropriate emission factors, use the gray arrows to navigate to the Liming of Soils worksheet.

Liming of Soils Worksheet

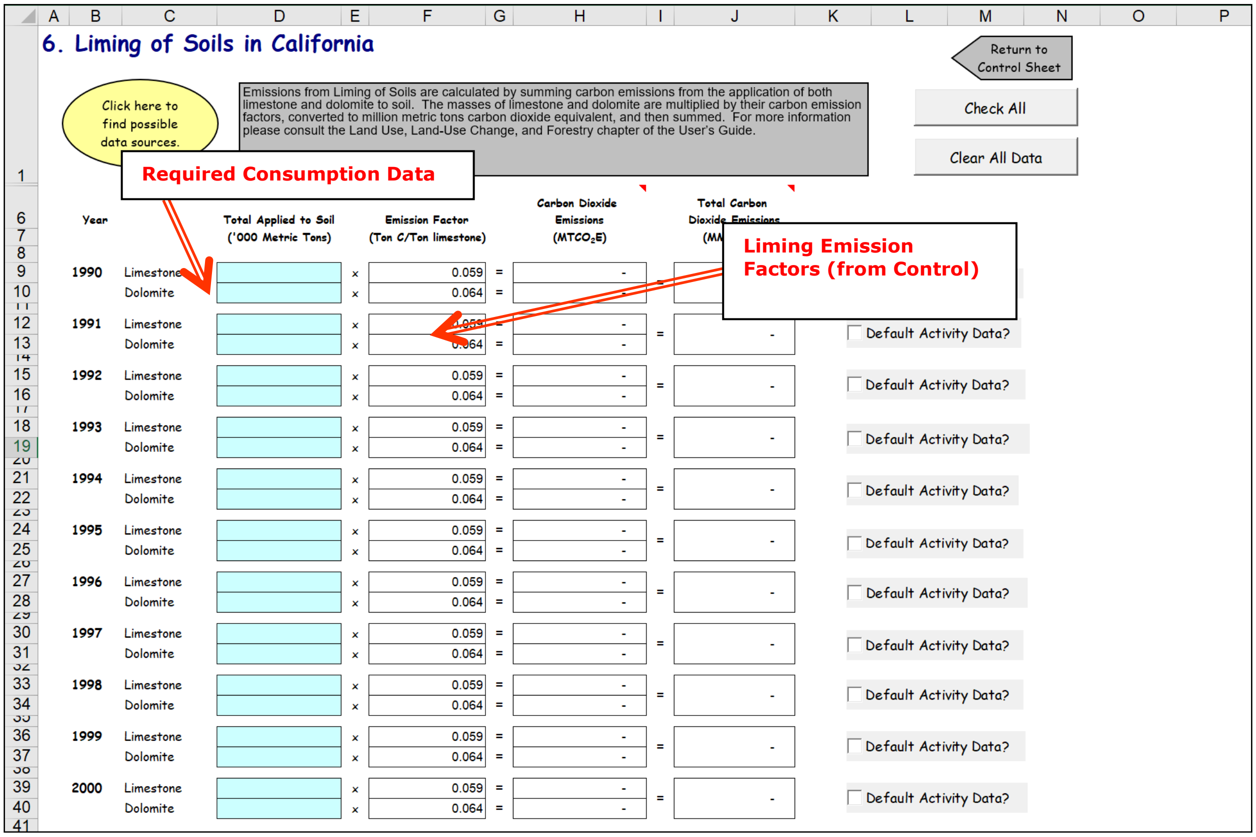
Within the Liming of Soils worksheet, enter the total limestone and dolomite applied to soil in the light blue cells, in thousands of metric tons. An example of this worksheet is shown in Figure 12. Equation 10 shows the method used to calculate CO_2 emissions from liming of soils.

Default data are provided for most states if you wish to use them; however, states are encouraged to use more detailed data if it is available and well documented. The default data are from the United States Geological Survey (USGS 2024). Once this worksheet is complete, use the gray navigational arrow to return to the control worksheet and proceed to the next source category.

Equation 10. Emission Equation for Liming of Soils

Emissions ($MMTCO_2E$) =
Total Limestone or Dolomite Applied to Soil (1,000 metric tons) × Emission Factor (tons C/ton limestone or dolomite) × 44/12 (ratio of CO_2 to C) ÷ 1,000,000 (to yield $MMTCO_2E$)

Figure 12. Example of Data Applied in the Liming of Soils Worksheet



Step (7) Enter Emission Factors and Activity Data for Urea Fertilization Control Worksheet

The data entered in the control worksheet for this sector is an emission factor for urea application as a fertilizer to soils. The emission factor should be in metric tons of carbon per metric ton of urea. The default emission factor is based on IPCC (2006); if emission factors other than module defaults are available for urea fertilization, you should document their source carefully. If the user-specific inputs do not match the default data in the control worksheet (i.e., the default value is overwritten), the text will appear red.

Urea is used as a fertilizer that results in CO_2 emissions that were fixed during the industrial production process. According to U.S. EPA (2024a), urea in the presence of water and urease enzymes is converted into ammonium (NH_4^+), hydroxyl ion (OH^-), and bicarbonate (HCO_3^-). The bicarbonate then evolves into CO_2 and water. This section presents the methodology for calculating the CO_2 emissions from the application of urea to soils.

After entering the appropriate emission factors, use the gray arrows to navigate to the Urea Fertilization worksheet.

Urea Fertilization Worksheet

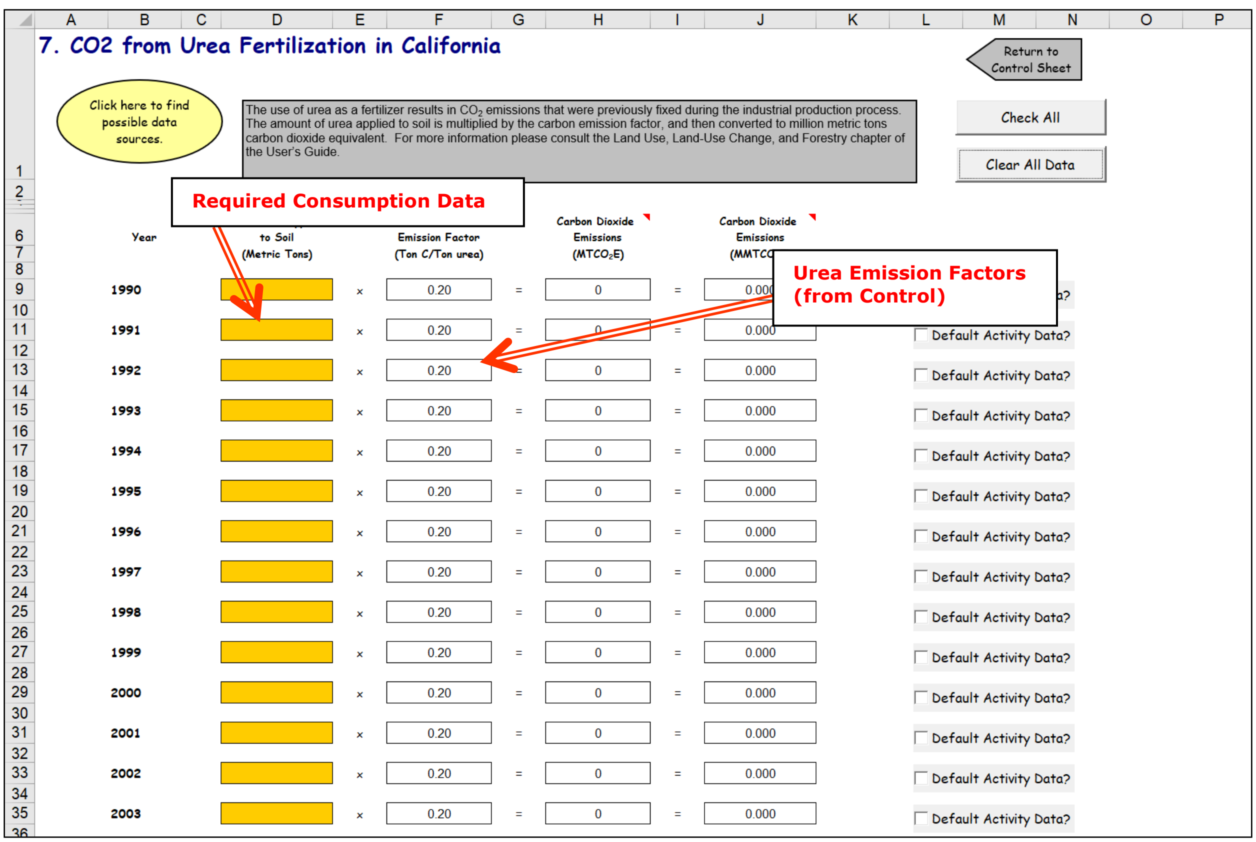
Within the Urea Fertilization worksheet, enter the total urea applied to soil in the orange cells, in metric tons. An example of this worksheet is shown in Figure 13. Equation 11 shows the method used to calculate CO_2 emissions from the application of urea to soils.

Default data are provided for most states if you wish to use them; however, states are encouraged to use more detailed data if it is available and well documented. The default data on the amount of fertilizer applied were derived from state-level fertilizer sales data provided in TVA (1991 through 1994) and AAPFCO (2021). Once this worksheet is complete, use the gray navigational arrow to return to the control worksheet and proceed to the next source category.

Equation 11. Emission Equation for Urea Fertilization

Emissions ($MMTCO_2E$) =
Total Urea Applied to Soil (metric tons) × Emission Factor (tons C/ton urea) × 44/12 (ratio of CO_2 to C) ÷ 1,000,000 (to yield $MMTCO_2E$)

Figure 13. Example of Data Applied in the Urea Fertilization Worksheet



Step (8) Enter Emission Factors and Activity Data for Agricultural Residue Burning

Control Worksheet

Agricultural production results in large quantities of crop wastes. In some parts of the United States, these residues are burned in the field to clear remaining straw and stubble after harvest, and to prepare the field for the next cropping cycle. This process releases CO_2, CH_4, and N_2O. In accordance with international greenhouse gas (GHG) accounting guidelines, the Ag module does not include CO_2 emissions from crop residue burning. This is because the carbon released as carbon dioxide during burning had been taken up from carbon dioxide in the atmosphere during the growing season, thus resulting in no net emissions. This sector addresses emissions from burning residues of seven crops for which burning of crop wastes is significant in the United States—barley, corn, peanuts, rice, soybeans, sugarcane, and wheat. The data for agricultural residue burning is required by crop type in the control worksheet and includes:

- residue to crop ratio;
- fraction of residue burned, defined as the proportion of the total crop produced in fields where residue is burned;
- burning efficiency, defined as the fraction of dry biomass exposed to burning that actually burns;
- combustion efficiency, defined as the fraction of carbon in the fire that is released to the atmosphere; and
- carbon (C) content of the crops.

In addition, the dry matter fraction and the N content data from the agricultural soils sector are used for all crops except sugarcane, which is required here, if applicable. These data are pulled into the CH_4 and N_2O agricultural residue burning worksheets. After completing the control worksheet for this sector, use the gray arrows to navigate to the sector worksheets.

Agricultural Residue Burning Sector Worksheets

The information needed to estimate GHG emissions from burning of agricultural wastes is the annual production of barley, corn, peanuts, rice, soybeans, sugarcane, and wheat. In addition, the user has the option of entering the required data in the orange input cells for up to two additional unspecified crops per year. The SIT provides a conversion to metric tons from pounds of peanuts, hundred count of rice, tons of sugarcane, and bushels of barley, corn, soybeans, and wheat. The red arrows in Figure 14 and Figure 15 demonstrate the use of activity data to calculate agricultural residue burning emissions from CH_4 and N_2O, respectively.

Figure 14. Example of Activity Data Applied in the Agricultural Residue Burning CH_4 Worksheet

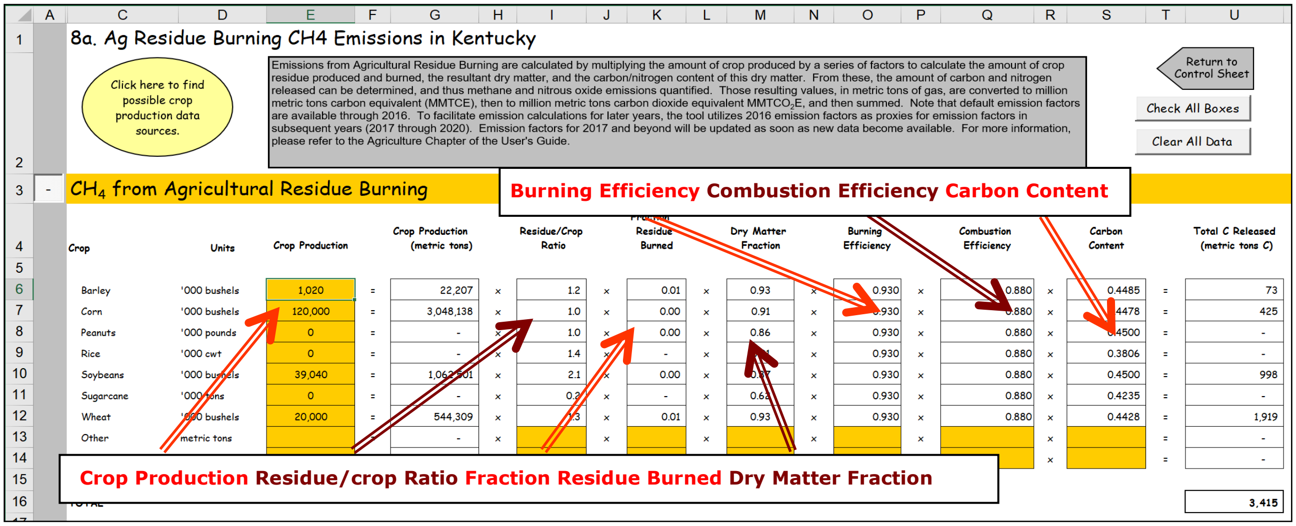
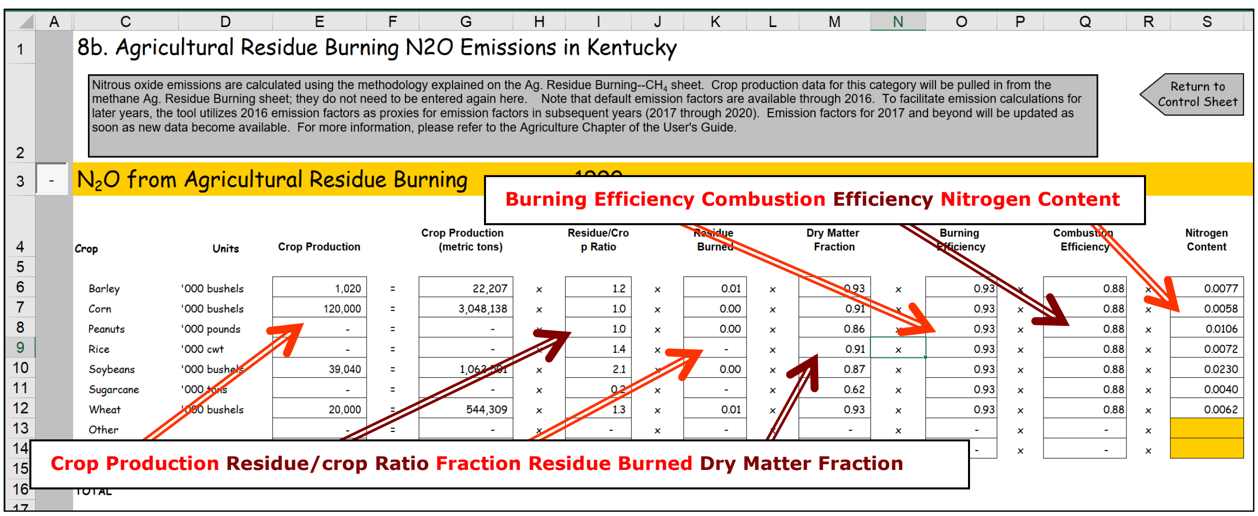


Figure 15. Example of the Agricultural Residue Burning N_2O Worksheet



The first step in estimating emissions from both CH_4 and N_2O from agricultural residue burning is to multiply crop production by the residue/crop ratio, proportion of residue burned, proportion of dry matter, burning efficiency, and combustion efficiency. This determines the total mass of dry matter combusted.

To then estimate CH_4 emissions, the dry matter combusted is multiplied by the fraction of C in the residue to estimate the total amount of C released, which is multiplied by the emission ratio of CH_4 relative to total C (0.005) to determine emissions of CH_4 in units of carbon (CH_4-C). Finally, emissions of CH_4-C are converted to full molecular weights for CH_4 emissions by multiplying by the mass ratio of CH_4 to C (16/12).

Similarly for N_2O emissions, the total dry matter combusted is multiplied by the ratio of N to dry matter in the crop residues to estimate total N released, which is multiplied by the N_2O-

N emission ratio (0.007) and converted to full molecular weight of N_2O by multiplying by (44/28), the mass ratio of N_2O to N.

Finally, for both CH_4 and N_2O emissions, the results are converted to $MMTCO_2E$ by multiplying by the GWP of CH_4 (28) or N_2O (265) and dividing by 10^6 to convert from metric tons to million metric tons, as shown in Equation 12.

Equation 12. General Emission Equation for Agricultural Residue Burning

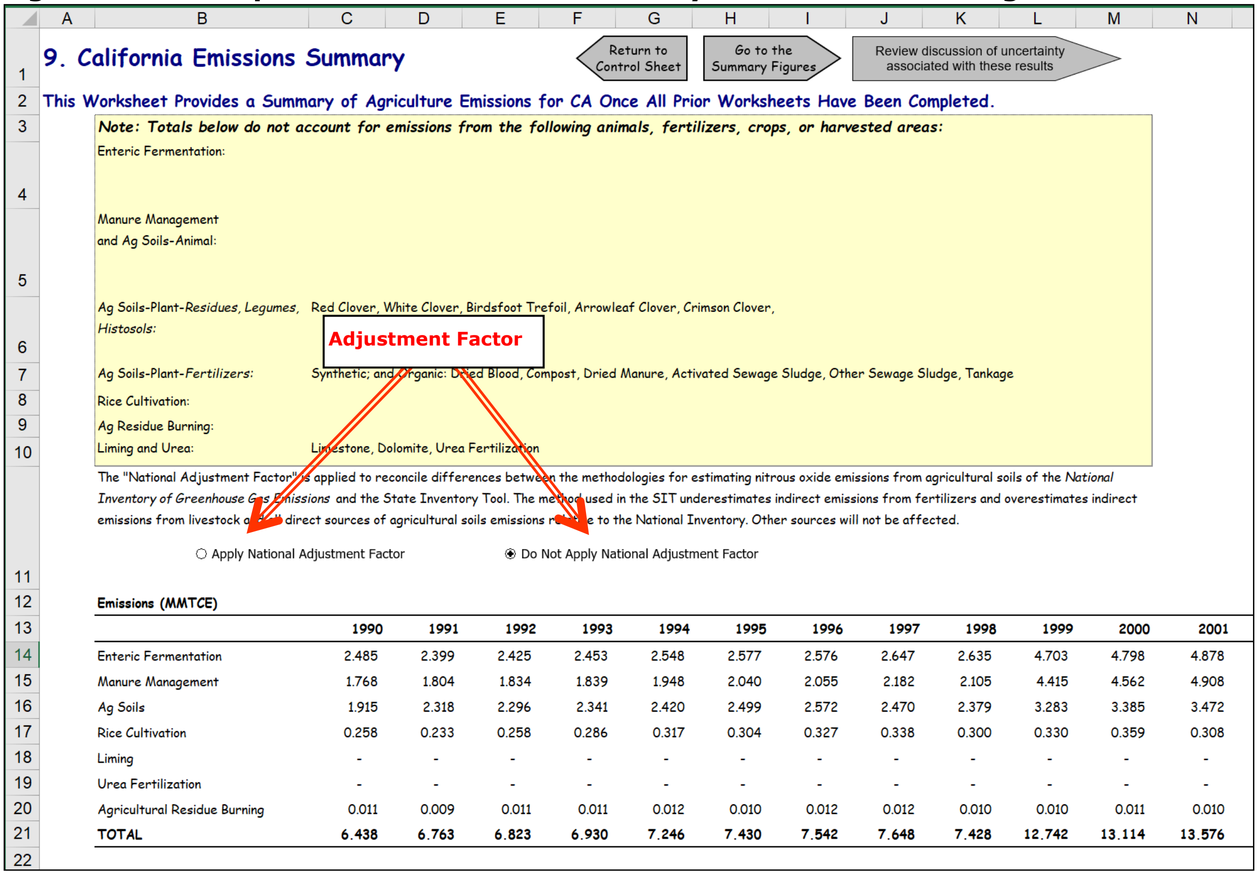
Emissions (($MMTCO_2E$) =
Crop Production (metric tons) × Residue/Crop Ratio × Fraction Residue Burned Dry Matter Fraction × Burning Efficiency × Combustion Efficiency × C or N Content × Emission Ratio (CH_4-C or N_2O-N) × Mass Ratio (CH_4/C or N_2O/N) × GWP ÷ 1,000,000 (MT/($MMTCO_2E$)

Once this sector worksheet is complete, use the gray navigational arrow to return to the control worksheet and proceed to the next sector.

Step (9) Review Summary Information

The steps above provide estimates of total CO_2, CH_4, and N_2O emissions from each agricultural sector. Total emissions are equal to sum of emissions from each livestock or crop type, for each year. The information is collected by sector on the summary worksheets. There are two summary worksheets in the Ag module, one that displays results in both $MMTCO_2E$ and MMTCE, and a second that displays the results in graphical format. Additionally, the summary worksheet provides an overview of sources excluded from the current emission estimates. Users should check this list to see if they wish to go back and enter data for any of the omitted crop or livestock types. Figure 16 shows the summary worksheet that sums the emissions from all sectors in the Ag module. In the summary worksheet, users can choose to apply the "National Adjustment Factor," which helps reconcile differences between the methodologies for estimating N_2O emissions from agricultural soils of the National Inventory of Greenhouse Gas Emissions and the SIT. Specifically, the method used in the SIT underestimates indirect emissions from fertilizers while overestimating indirect emissions from livestock and all direct sources of agricultural soils emissions, relative to the National Inventory. Using the adjustment factor will only affect estimates of agricultural soils.

Figure 16. Example of the Emissions Summary Worksheet in the Ag Module



9. California Emissions Summary

Return to Control Sheet | Go to the Summary Figures | Review discussion of uncertainty associated with these results

This Worksheet Provides a Summary of Agriculture Emissions for CA Once All Prior Worksheets Have Been Completed.

Note: Totals below do not account for emissions from the following animals, fertilizers, crops, or harvested areas:

Enteric Fermentation:

Manure Management and Ag Soils-Animal:

Ag Soils-Plant-*Residues, Legumes, Histosols:* Red Clover, White Clover, Birdsfoot Trefoil, Arrowleaf Clover, Crimson Clover,

Adjustment Factor

Ag Soils-Plant-*Fertilizers:* Synthetic; and Organic: Dried Blood, Compost, Dried Manure, Activated Sewage Sludge, Other Sewage Sludge, Tankage

Rice Cultivation:

Ag Residue Burning:

Liming and Urea: Limestone, Dolomite, Urea Fertilization

The "National Adjustment Factor" is applied to reconcile differences between the methodologies for estimating nitrous oxide emissions from agricultural soils of the *National Inventory of Greenhouse Gas Emissions* and the State Inventory Tool. The method used in the SIT underestimates indirect emissions from fertilizers and overestimates indirect emissions from livestock and all direct sources of agricultural soils emissions relative to the National Inventory. Other sources will not be affected.

○ Apply National Adjustment Factor ◉ Do Not Apply National Adjustment Factor

Emissions (MMTCE)

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001
Enteric Fermentation	2.485	2.399	2.425	2.453	2.548	2.577	2.576	2.647	2.635	4.703	4.798	4.878
Manure Management	1.768	1.804	1.834	1.839	1.948	2.040	2.055	2.182	2.105	4.415	4.562	4.908
Ag Soils	1.915	2.318	2.296	2.341	2.420	2.499	2.572	2.470	2.379	3.283	3.385	3.472
Rice Cultivation	0.258	0.233	0.258	0.286	0.317	0.304	0.327	0.338	0.300	0.330	0.359	0.308
Liming	-	-	-	-	-	-	-	-	-	-	-	-
Urea Fertilization	-	-	-	-	-	-	-	-	-	-	-	-
Agricultural Residue Burning	0.011	0.009	0.011	0.011	0.012	0.010	0.012	0.012	0.010	0.010	0.011	0.010
TOTAL	**6.438**	**6.763**	**6.823**	**6.930**	**7.246**	**7.430**	**7.542**	**7.648**	**7.428**	**12.742**	**13.114**	**13.576**

Step (10) Export Data

The final step is to export the summary data. Exporting data allows the estimates from each module to be combined later by the Synthesis Module to produce a comprehensive GHG inventory for the state.

To access the "Export Data" button, return to the control worksheet and scroll down to step 10. Click on the "Export Data" button and a message box will open that reminds the user to make sure all sections of the module have been completed. If you make any changes to the Ag module later, you will then need to re-export the results.

Clicking "OK" prompts you to save the file. The file is already named, so you only need to choose a convenient place to save the file. After the file is saved, a message box will appear indicating that the data was successfully exported.

While completing the modules, you are encouraged to save each completed module; doing so will enable you to easily make changes without re-running it entirely.

Note: the resulting export file should not be modified. The export file contains a summary worksheet that allows users to view the results, as well as a separate data worksheet with an unformatted version of the results. The second worksheet, the data worksheet, contains the information that is exported to the Synthesis Tool. Users may not modify that worksheet. Adding/removing rows, moving data, or making other modifications jeopardize the ability of the Synthesis Module to accurately analyze the data.

Following data export, the module may be reset and run for an additional state. Alternatively, you may run the remaining modules of the SIT to obtain a comprehensive profile of emissions for your state.

1.4 Uncertainty

In the upper right-hand corner of the summary worksheet is a button: "Review discussion of uncertainty associated with these results." By clicking on this button, you are taken to a worksheet that discusses the uncertainty surrounding the activity data and emission factors, and how the uncertainty estimates for this source category affect the uncertainty of the emission estimates for your state.

1.5 References

AAPFCO. 2021. Commercial Fertilizers 2016. Association of American Plant Food Control Officials and The Fertilizer Institute. University of Kentucky, Lexington, KY.

U.S. EPA. 2024a. Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990 – 2022. Office of Atmospheric Protection, U.S. Environmental Protection Agency, EPA 430R-24-004. Available at: https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks.

U.S. EPA. 2024b. Inventory of U.S. Greenhouse Gas Emissions and Sinks By State: 1990 – 2022. Office of Atmospheric Protection, U.S. Environmental Protection Agency. Available at: https://www.epa.gov/ghgemissions/state-ghg-emissions-and-removals.

Carpenter, G.H. 1992. "Current litter practices and future needs." 1992 National Poultry Waste Management Symposium. Auburn University Printing Service. Auburn, Al.

Holzapfel-Pschorn, A., R. Conrad, and W. Seiler. 1985. Production, oxidation, and emission of methane in rice paddies. FEMS Microbiology Ecology 31:343-351.

IPCC. 2006. 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Volume 4: Agriculture, Forestry, and Other Land Use. The National Greenhouse Gas Inventories Programme, The Intergovernmental Panel on Climate Change. [H.S. Eggleston, L. Buendia, K. Miwa, T. Ngara, and K. Tanabe (eds.)]. Hayama, Kanagawa, Japan.

IPCC. 1997. IPCC Guidelines for National Greenhouse Gas Inventories, 3 volumes: Vol. 1, Reporting Instructions; Vol. 2, Workbook; Vol. 3, Draft Reference Manual. Intergovernmental Panel on Climate Change, Organization for Economic Co-Operation and Development. Paris, France.

Lindau, C.W. and P.K. Bollich. 1993. "Methane Emissions from Louisiana First and Ratoon Crop Rice." Soil Science 156: 42-48. July 1993.

Sass, R.L., F.M. Fisher, P.A. Harcombe, and F.T. Turner. 1990. "Methane production and emission in a Texas rice field." Global Biogeochemical Cycles 4:47-68.

TVA. 1991 through 1994. Commercial Fertilizers. Tennessee Valley Authority, Muscle Shoals, AL.

U.S. Geological Survey. 2024. "Crushed Stone," 2022 Minerals Yearbook. U.S. Department of the Interior/U.S. Geological Survey, Washington, D.C. Available online at: https://www.usgs.gov/centers/nmic/crushed-stone-statistics-and-information#myb.

West, T.O., and A.C. McBride. 2005. "The contribution of agricultural lime to carbon dioxide emissions in the United States: dissolution, transport, and net emissions," *Agricultural Ecosystems & Environment* 108:145-154.