# User's Guide for Estimating Carbon Dioxide, Methane, and Nitrous Oxide Emissions from Agriculture Using the State Inventory Tool

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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.

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## 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

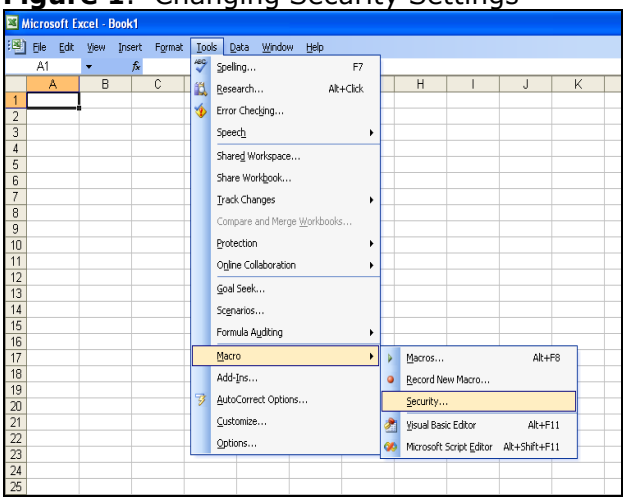
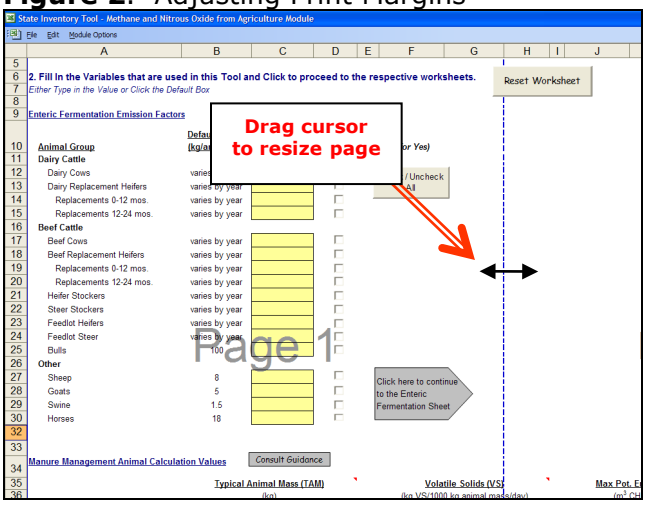



**Figure 2**. Adjusting Print Margins




## 1.2 Module Overview

This User's Guide accompanies and explains the Agriculture module of the SIT. The SIT was developed in conjunction with EPA's Emissions Inventory Improvement Program (EIIP). Prior to the development of the SIT, EPA developed the States Workbook for estimating greenhouse gas emissions. In 1998, EPA revisited the States Workbook and expanded it to

follow the format of EIIP guidance documents for criteria air pollutants. The result was a comprehensive, stepwise approach to estimating greenhouse gas emissions at the state level. This detailed methodology was appreciated by states with the capacity to devote considerable time and resources to the development of emission inventories. For other states, the EIIP guidance was overwhelming and impractical for them to follow from scratch. EPA recognized the resource constraints facing the states and developed the SIT. The ten modules of the SIT corresponded to the EIIP chapters and attempted 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.

Because most state inventories developed today rely heavily on the tools, 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. Volume VIII of the EIIP guidance is a historical document that was last updated in August 2004, and while these documents can be a valuable reference, they contain outdated emissions factors and, in some cases, outdated methodologies. States can refer to Volume VIII of the EIIP guidance documents if they are interested in obtaining additional information not found in the SIT or the companion User's Guide.

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**

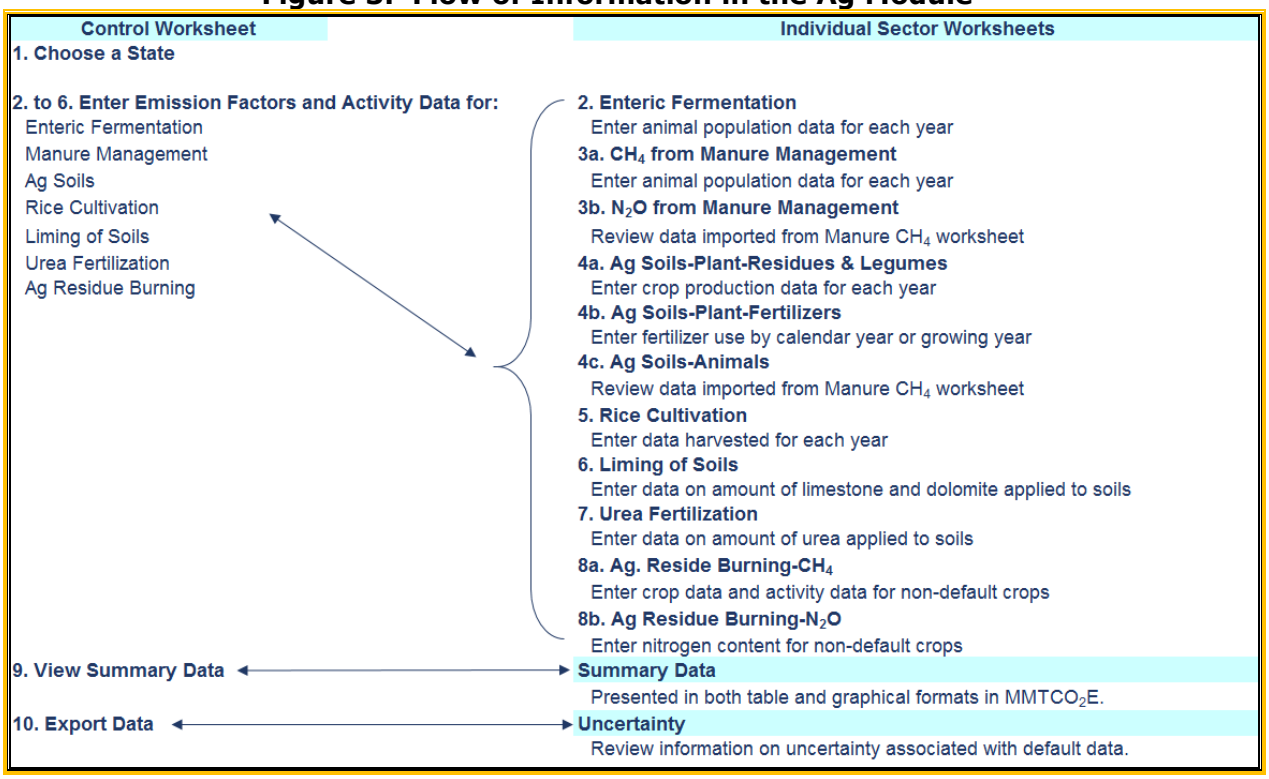
| Module Worksheet | Data Required | Gas(es) |
|---|---|---|
| Enteric Fermentation | Emission Factors by Animal Type<br>Animal Population Numbers | $CH_4$ |
| Manure Management-$CH_4$<br>Manure Management-$N_2O$ | Typical Animal Mass (TAM)<br>Volatile Solids (VS) Production<br>Maximum Potential $CH_4$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




* 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 outlined in Chapters VII through XI of the Emissions Inventory Improvement Program (EIIP) guidance, however because of the automation of the calculations within the tool, the order of steps discussed in this User's

Guide do not always follow the order of steps discussed within the EIIP guidance document. 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

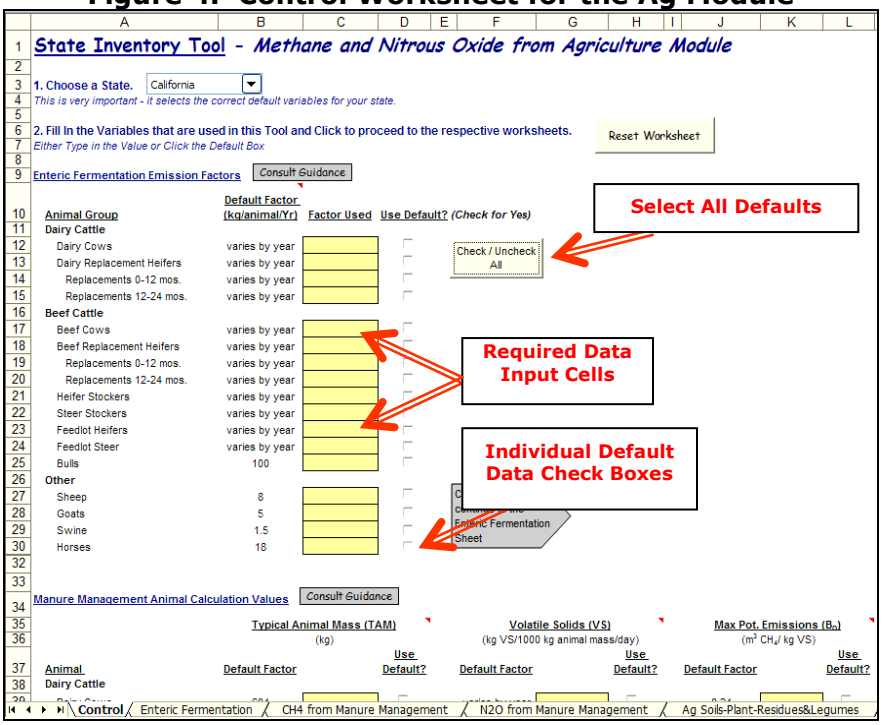
To begin, select the state you are interested in evaluating. By selecting a state, the rest of the tool will automatically reset to reflect the appropriate state default data and assumptions for use in subsequent steps of the tool.

### 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**

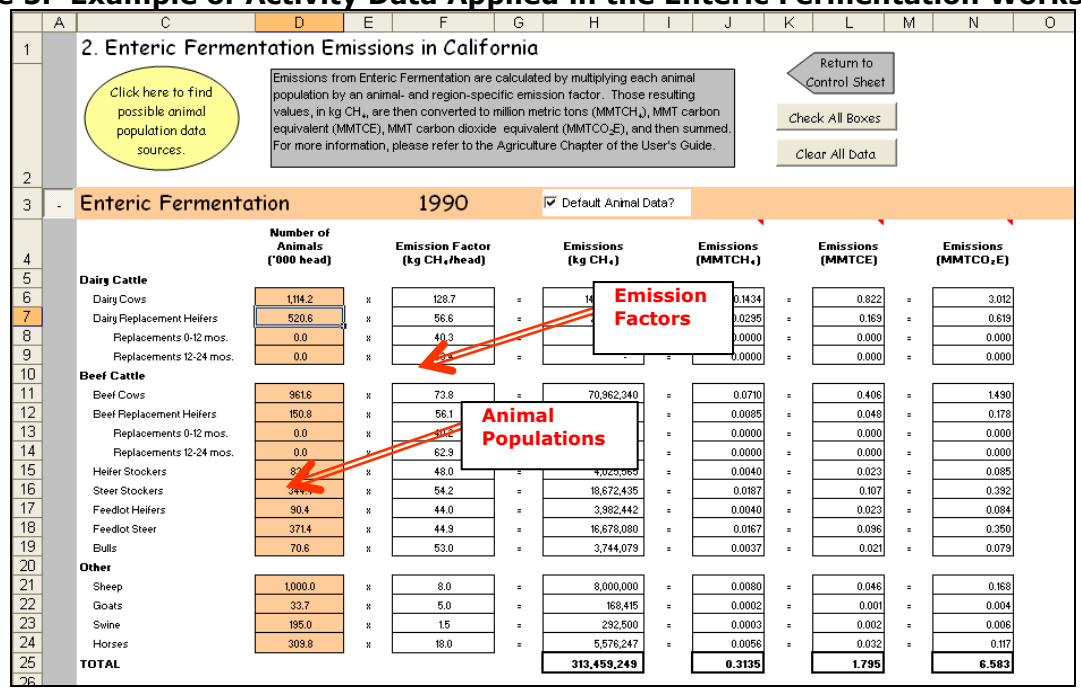



The first type of required data in the control worksheet is emission factors by animal type for enteric fermentation. $CH_4$ is produced as part of the normal digestive processes of animals. The amount of $CH_4$ produced by domesticated animals depends primarily on the type of animal (e.g., ruminant 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 (2021). Default emission factors for other livestock types do not vary by animal production characteristics and are also from EPA (2021). 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?

Emission Factors

Animal Populations

| | 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 | = | 14 | | 0.1434 | = | 0.822 | = | 3.012 |
| Dairy Replacement Heifers | 520.6 | x | 56.6 | = | | | 0.0295 | = | 0.169 | = | 0.619 |
| Replacements 0-12 mos. | 0.0 | x | 40.3 | = | | | 0.0000 | = | 0.000 | = | 0.000 |
| Replacements 12-24 mos. | 0.0 | x | | = | | = | 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 | = | | = | 0.0085 | = | 0.048 | = | 0.178 |
| Replacements 0-12 mos. | 0.0 | x | | = | | = | 0.0000 | = | 0.000 | = | 0.000 |
| Replacements 12-24 mos. | 0.0 | x | 62.9 | = | | = | 0.0000 | = | 0.000 | = | 0.000 |
| Heifer Stockers | 83 | x | 48.0 | = | 4,026,069 | = | 0.0040 | = | 0.023 | = | 0.085 |
| Steer Stockers | 344.4 | 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 $CH_4$ (25). 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) × 25 (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 $CH_4$ (25). 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**

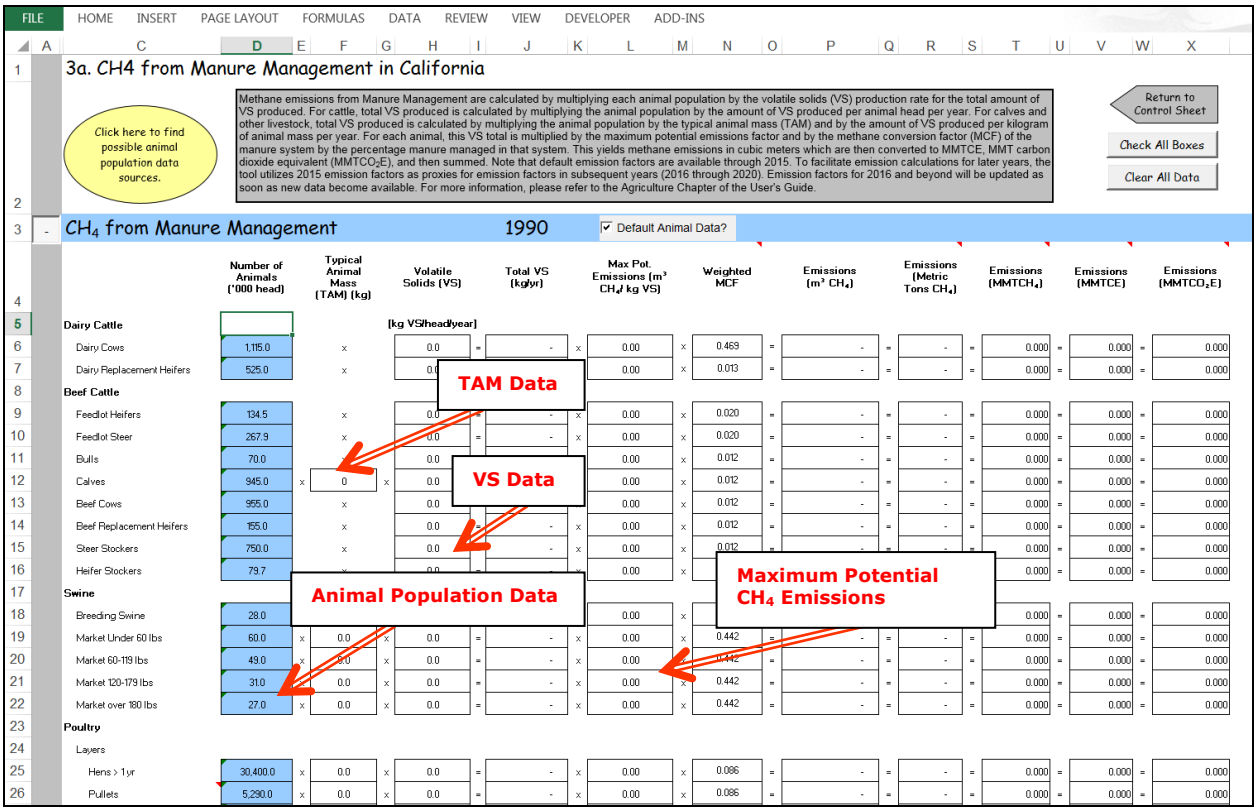
$$\text{VS Produced}_{\text{Cattle, excluding calves}} = \text{Animal Population (`000 head)} \times 1{,}000 \times \text{VS (kg/head/yr)}$$

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

$$\text{Emissions (MMTCO}_2\text{E)} = \text{VS Produced (kg)} \times B_o\ (m^3\ CH_4/\text{kg VS}) \times \text{MCF} \times 0.678\ \text{kg}/m^3 \times 25\ \text{(GWP)} \div 1{,}000{,}000{,}000\ (MMTCO_2E)$$

[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 $N_2O$ (298) 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**

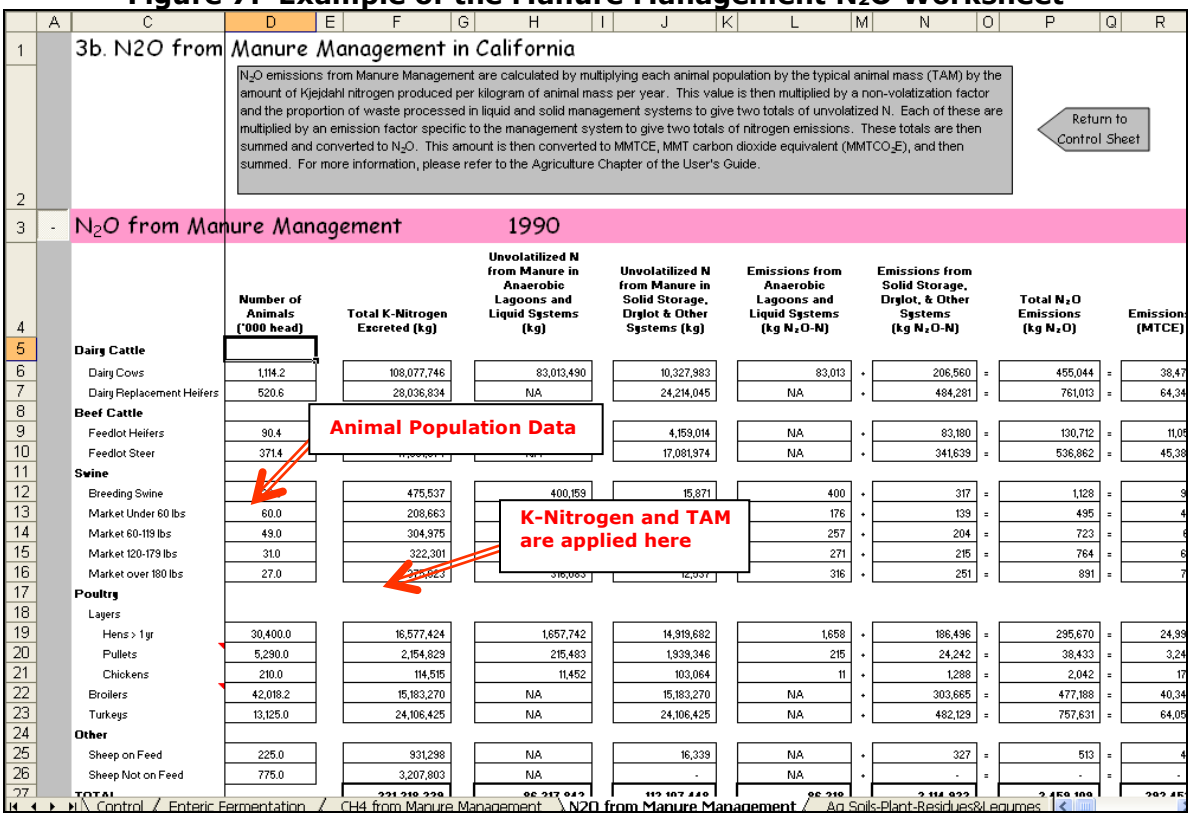
$$\textbf{K-Nitrogen Excreted}_{\textbf{Cattle, excluding calves}} = \textbf{Animal Population ('000 head)} \times \textbf{1,000} \times \textbf{K-Nitrogen (kg/head/day)}$$

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

$$\textbf{Emissions (MMTCO}_2\textbf{E)} = \textbf{K-Nitrogen Excreted} \times \textbf{Emission Factor (liquid or dry)} \times \textbf{298 (GWP)} \div \textbf{1,000,000,000 (kg/MMTCO}_2\textbf{E)}$$

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**



3b. N2O from Manure Management in California

$N_2O$ emissions from Manure Management are calculated by multiplying each animal population by the typical animal mass (TAM) by the amount of Kjejdahl nitrogen produced per kilogram of animal mass per year. This value is then multiplied by a non-volatization factor and the proportion of waste processed in liquid and solid management systems to give two totals of unvolatized N. Each of these are multiplied by an emission factor specific to the management system to give two totals of nitrogen emissions. These totals are then summed and converted to $N_2O$. This amount is then converted to 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

$N_2O$ from Manure Management 1990

| | 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 $N_2O$) | | Emission (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 | | | 4,159,014 | NA | + | 83,180 | = | 130,712 | = | 11,05 |
| Feedlot Steer | 371.4 | | | 17,081,974 | NA | + | 341,639 | = | 536,862 | = | 45,38 |
| **Swine** | | | | | | | | | | | |
| Breeding Swine | | 475,537 | 400,159 | 15,871 | 400 | + | 317 | = | 1,128 | = | 9 |
| Market Under 60 lbs | 60.0 | 208,663 | | | 176 | + | 139 | = | 495 | = | 4 |
| Market 60-119 lbs | 49.0 | 304,975 | | | 257 | + | 204 | = | 723 | = | 6 |
| Market 120-179 lbs | 31.0 | 322,301 | | | 271 | + | 215 | = | 764 | = | 6 |
| Market over 180 lbs | 27.0 | | | | 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 | + | - | = | - | = | - |

Animal Population Data

K-Nitrogen and TAM are applied here

Control / Enteric Fermentation / CH4 from Manure Management / N2O from Manure Management / Ag Soils-Plant-Residues&Legumes

## 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.

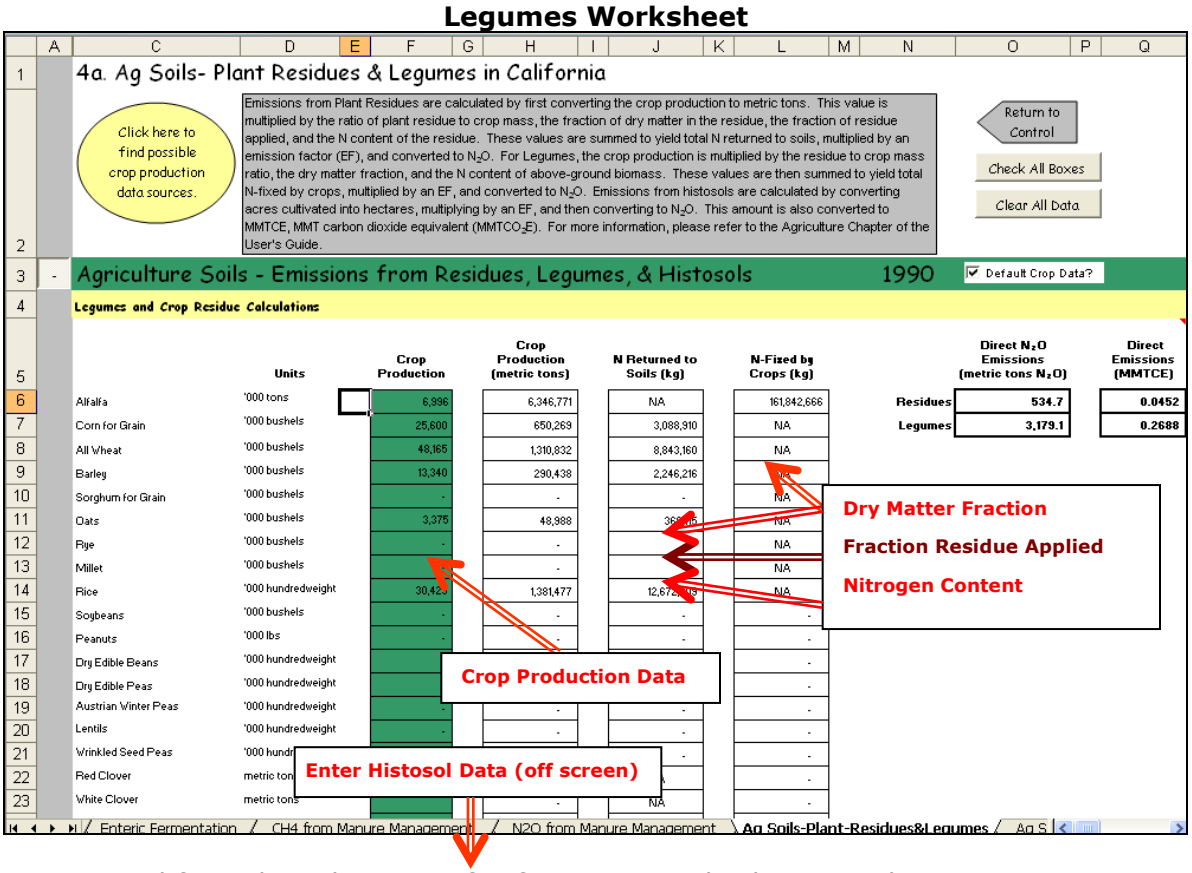
residue dry matter fraction, fraction residue applied, and nitrogen (N) content of residue. Crop types utilized include alfalfa, corn for grain, all wheat, barley, sorghum, oats, rye, millet, rice, soybeans, peanuts, dry edible beans, dry edible peas, austrian winter peas, lentils, and wrinkled seed 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 $N_2O$ (298) 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) × 298 (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 $N_2O$ (298) 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) × 298 (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 $N_2O$ (298) and dividing by $10^9$ to convert from kg to $MMTCO_2E$. Equation 6 shows emission calculations from N-fixing crops.

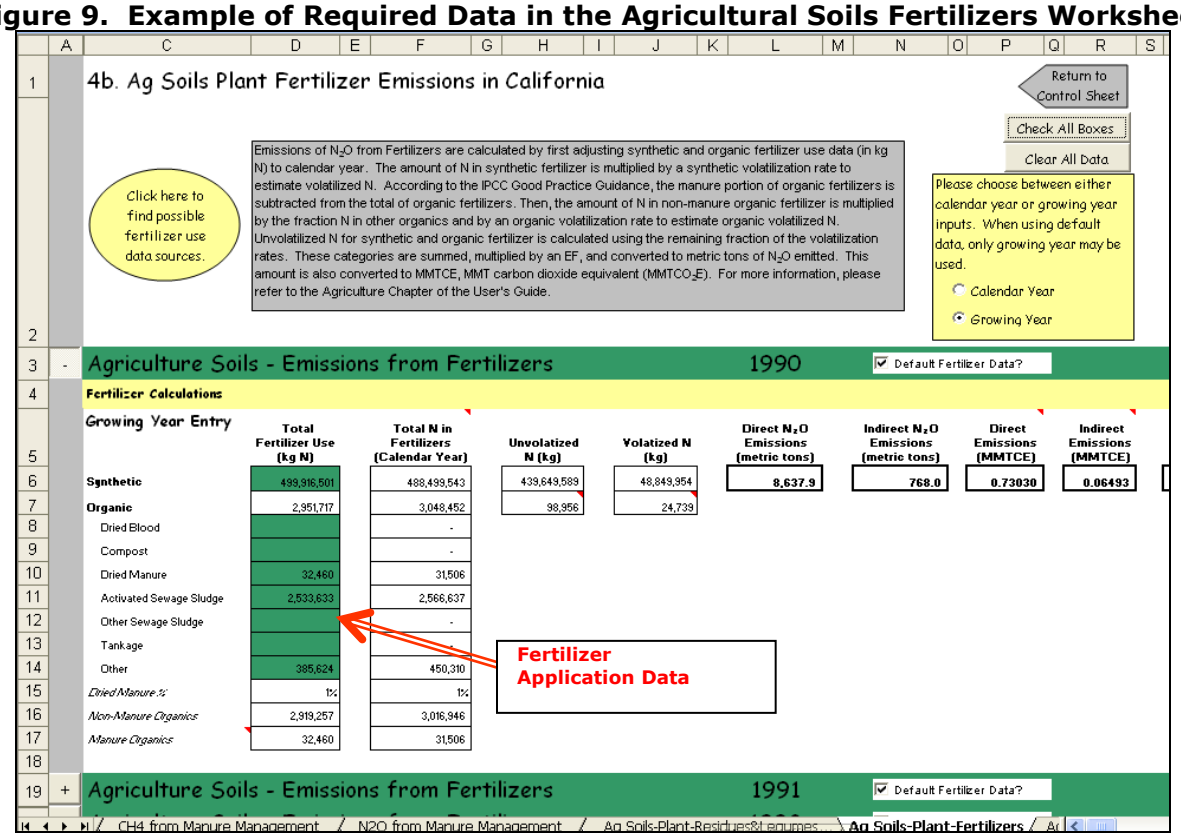
**Equation 6. Emission Equation for Histosols**

**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) × 298 (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 either a standard calendar year or the growing season year, however if the default data are used the SIT automatically is based on the growing year. 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

[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.

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 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 $N_2O$ (298) 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**

**Emissions ($MMTCO_2E$) =**
**Total N × fraction unvolatilized (0.9 synthetic or 0.8 organic)**
**× 0.01 (kg $N_2O$-N/kg N) × 44/28 (Ratio of $N_2O$ to $N_2O$-N) × 298 (GWP)**
**÷ 1,000,000,000 (kg/$MMTCO_2E$)**

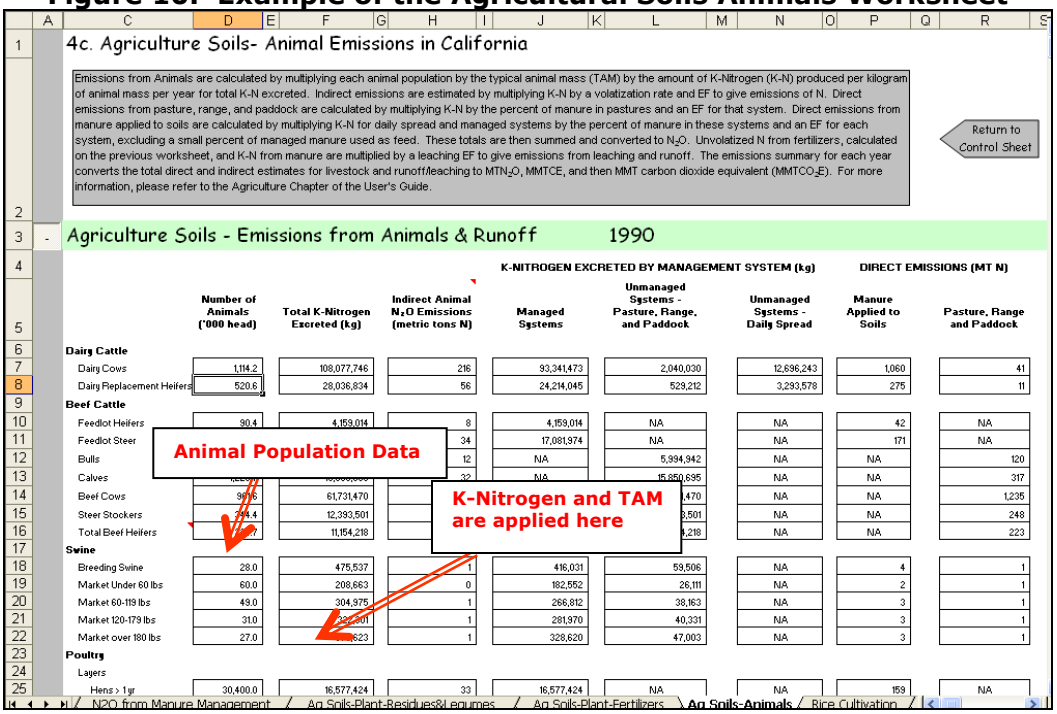
**Equation 8. Emission Equation for Indirect $N_2O$ Emissions from Agricultural Soils**

**Emissions ($MMTCO_2E$) =**
**Total N × fraction volatilized (0.1 synthetic or 0.2 organic)**
**× 0.001 (kg $N_2O$-N/kg N) × 44/28 (Ratio of $N_2O$ to $N_2O$-N) × 298 (GWP)**
**÷ 1,000,000,000 (kg/$MMTCO_2E$)**

### 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**



4c. Agriculture Soils- Animal Emissions in California

Emissions from Animals are calculated by multiplying each animal population by the typical animal mass (TAM) by the amount of K-Nitrogen (K-N) produced per kilogram of animal mass per year for total K-N excreted. Indirect emissions are estimated by multiplying K-N by a volatization rate and EF to give emissions of N. Direct emissions from pasture, range, and paddock are calculated by multiplying K-N by the percent of manure in pastures and an EF for that system. Direct emissions from manure applied to soils are calculated by multiplying K-N for daily spread and managed systems by the percent of manure in these systems and an EF for each system, excluding a small percent of managed manure used as feed. These totals are then summed and converted to $N_2O$. Unvolatized N from fertilizers, calculated on the previous worksheet, and K-N from manure are multiplied by a leaching EF to give emissions from leaching and runoff. The emissions summary for each year converts the total direct and indirect estimates for livestock and runoff/leaching to $MTN_2O$, MMTCE, and then MMT carbon dioxide equivalent ($MMTCO_2E$). For more information, please refer to the Agriculture Chapter of the User's Guide.

Return to Control Sheet

Agriculture Soils - Emissions from Animals & Runoff 1990

| | Number of Animals ('000 head) | Total K-Nitrogen Excreted (kg) | Indirect Animal $N_2O$ Emissions (metric tons N) | K-NITROGEN EXCRETED BY MANAGEMENT SYSTEM (kg): Managed Systems | Unmanaged Systems - Pasture, Range, and Paddock | Unmanaged Systems - Daily Spread | DIRECT EMISSIONS (MT N): Manure Applied to Soils | Pasture, Range and Paddock |
|---|---|---|---|---|---|---|---|---|
| **Dairy Cattle** | | | | | | | | |
| Dairy Cows | 1,114.2 | 108,077,746 | 216 | 93,341,473 | 2,040,030 | 12,696,243 | 1,060 | 41 |
| Dairy Replacement Heifers | 520.6 | 28,036,834 | 56 | 24,214,045 | 529,212 | 3,293,578 | 275 | 11 |
| **Beef Cattle** | | | | | | | | |
| Feedlot Heifers | 90.4 | 4,159,014 | 8 | 4,159,014 | NA | NA | 42 | NA |
| Feedlot Steer | [illegible] | [illegible] | 34 | 17,081,974 | NA | NA | 171 | NA |
| Bulls | [illegible] | [illegible] | 12 | NA | 5,994,942 | NA | NA | 120 |
| Calves | [illegible] | [illegible] | 32 | NA | 15,850,695 | NA | NA | 317 |
| Beef Cows | 9016 | 61,731,470 | [illegible] | [illegible] | [illegible] | NA | NA | 1,235 |
| Steer Stockers | [illegible] | 12,393,501 | [illegible] | [illegible] | [illegible] | NA | NA | 248 |
| Total Beef Heifers | [illegible] | 11,154,218 | [illegible] | [illegible] | [illegible] | NA | NA | 223 |
| **Swine** | | | | | | | | |
| Breeding Swine | 28.0 | 475,537 | 1 | 416,031 | 59,506 | NA | 4 | 1 |
| Market Under 60 lbs | 60.0 | 208,663 | 0 | 182,552 | 26,111 | NA | 2 | 1 |
| Market 60-119 lbs | 49.0 | 304,975 | 1 | 266,812 | 38,163 | NA | 3 | 1 |
| Market 120-179 lbs | 31.0 | [illegible] | 1 | 281,970 | 40,331 | NA | 3 | 1 |
| Market over 180 lbs | 27.0 | [illegible] | 1 | 328,620 | 47,003 | NA | 3 | 1 |
| **Poultry** | | | | | | | | |
| Layers | | | | | | | | |
| Hens > 1 yr | 30,400.0 | 16,577,424 | 33 | 16,577,424 | NA | NA | 159 | NA |



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 2021).

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, EPA 2021) 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 $N_2O$ (298) 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.

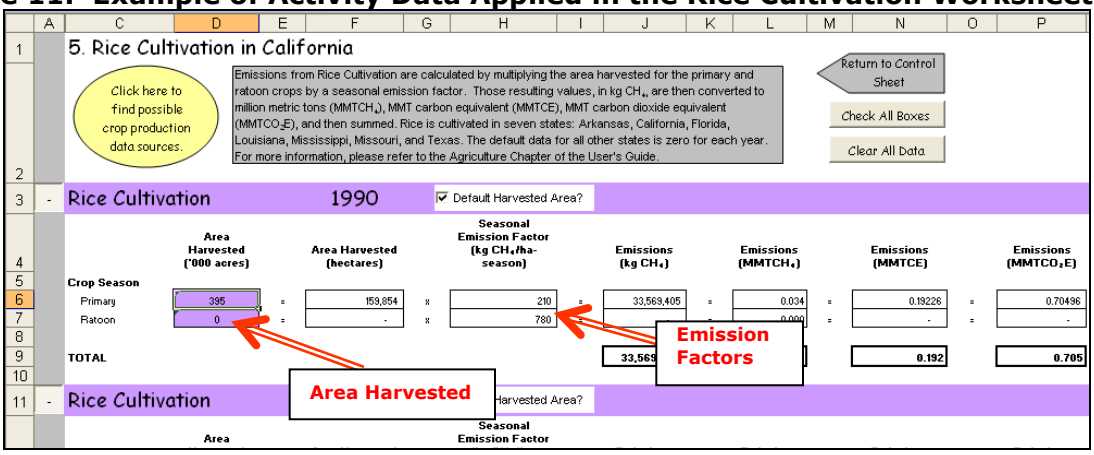
### Rice Cultivation Sector Worksheet

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 $CH_4$ (25) 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) × 25 (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

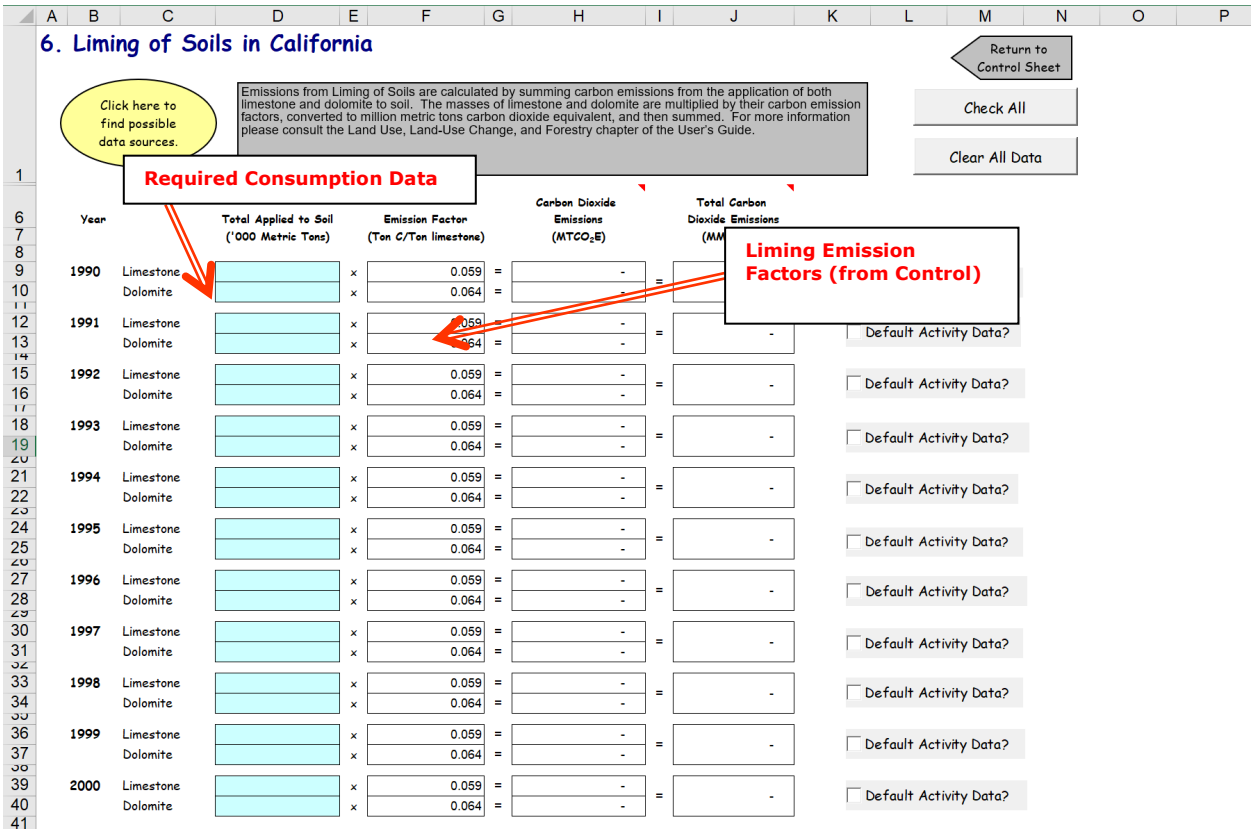
Within the Liming of Soils worksheet, enter the total limestone and dolomite applied to soil in the light blue cells, in thousands of metric tons. An example of this worksheet is shown in Figure 12. Equation 10 shows the method used to calculate $CO_2$ emissions from liming of soils.

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 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 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 (2021), 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

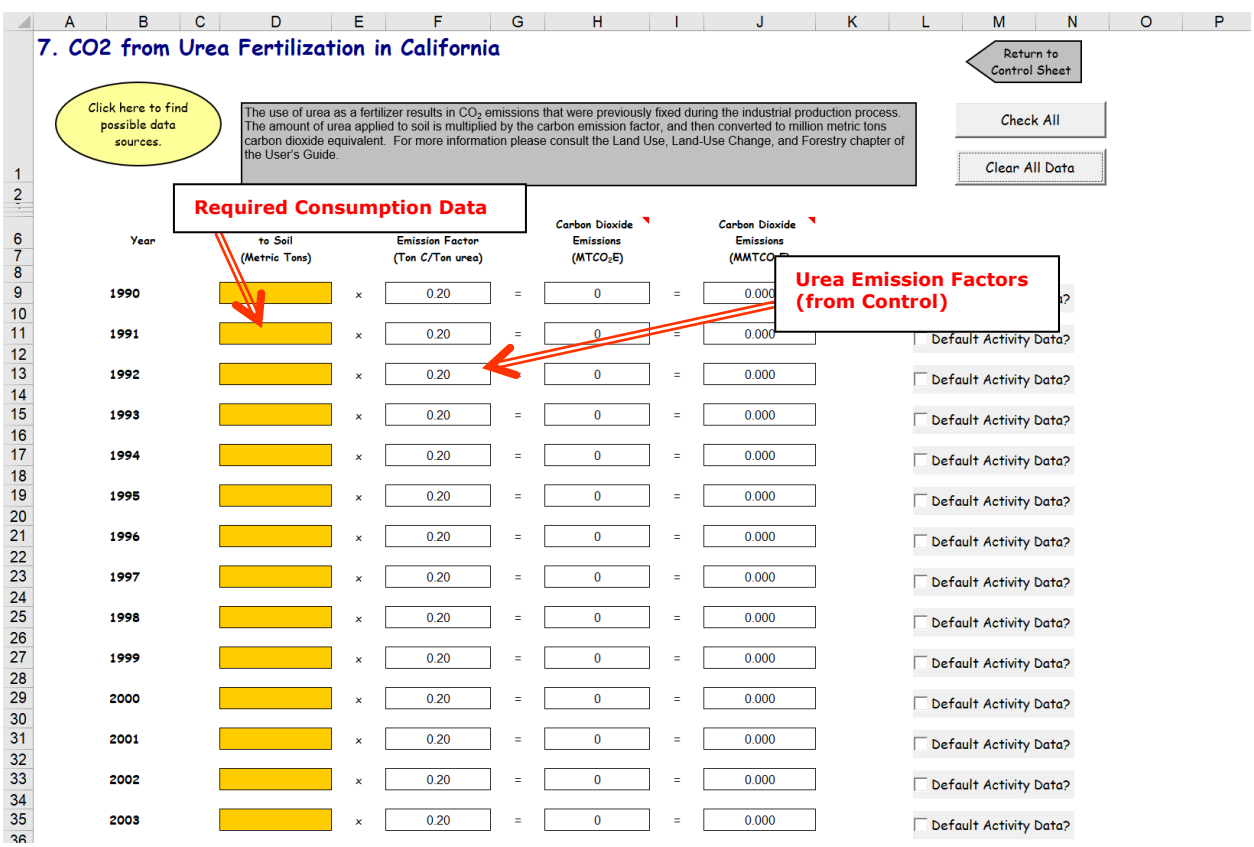
Within the Urea Fertilization worksheet, enter the total urea applied to soil in the orange cells, in metric tons. An example of this worksheet is shown in Figure 13. Equation 11 shows the method used to calculate $CO_2$ emissions from the application of urea to soils.

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 (2017). 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**

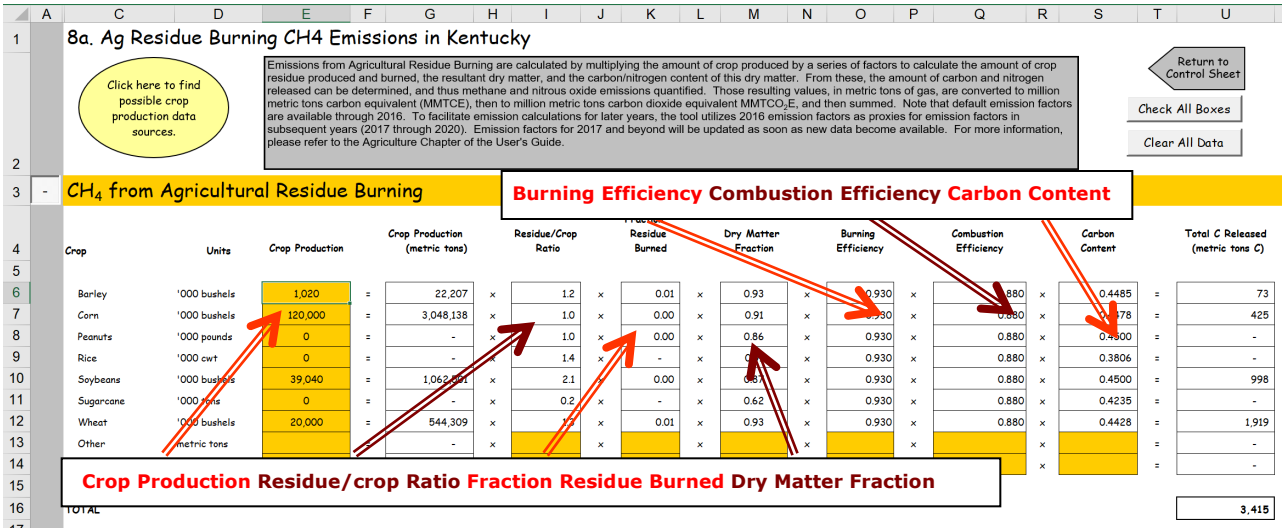
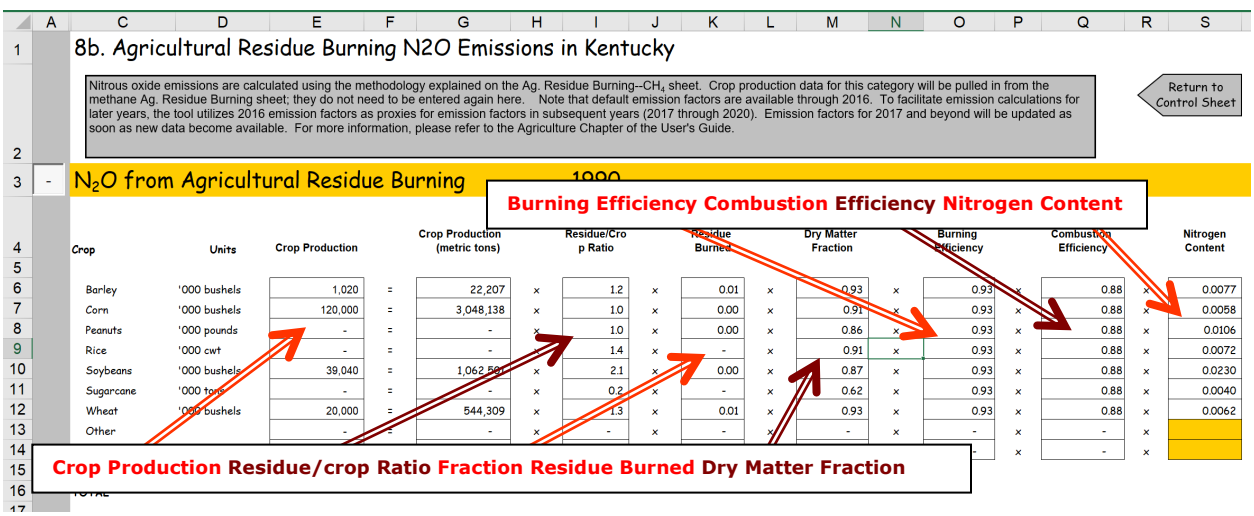



**Figure 15. Example of the Agricultural Residue Burning $N_2O$ Worksheet**




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 $CH_4$ (25) or $N_2O$ (298) 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**

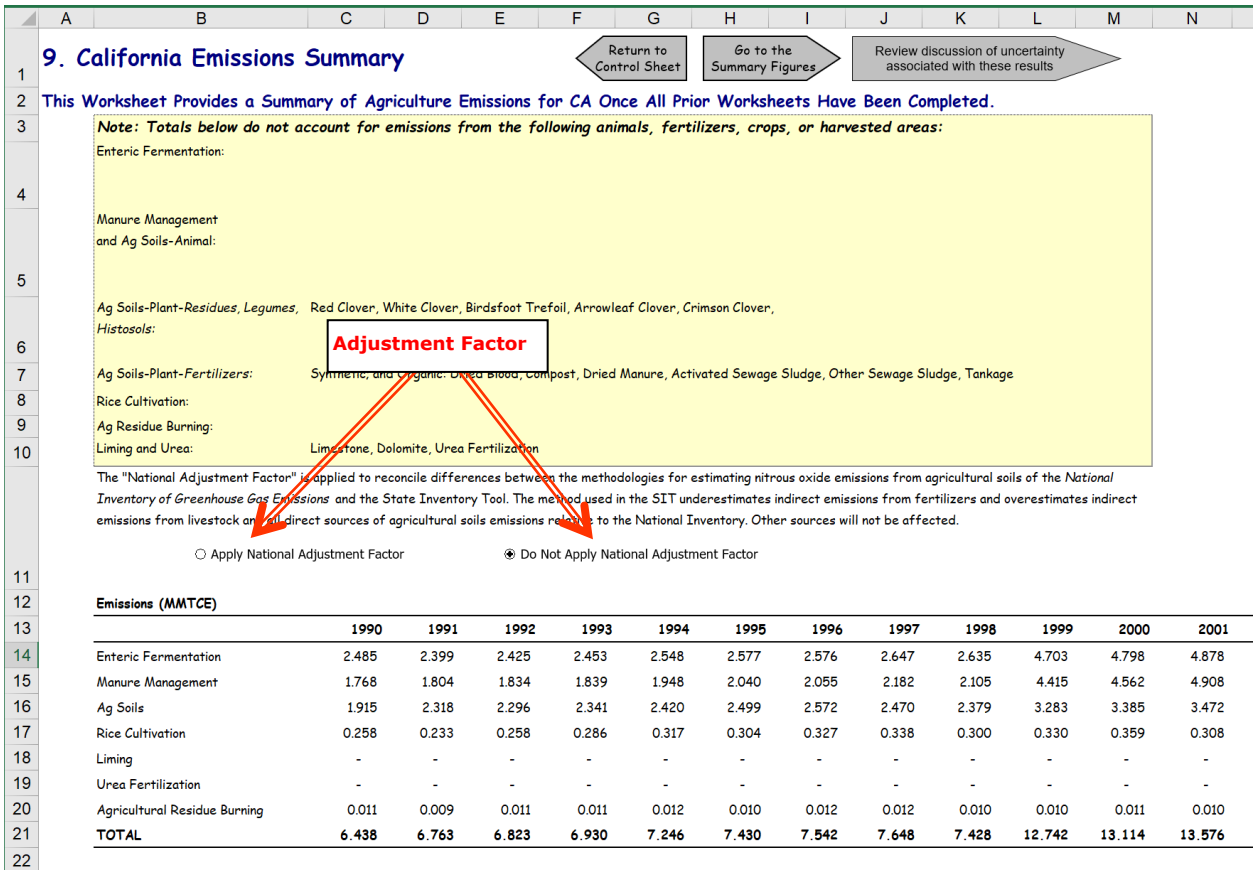
**Emissions ($(MMTCO_2E)$ =**
**Crop Production (metric tons) × Residue/Crop Ratio × Fraction Residue Burned Dry Matter Fraction × Burning Efficiency × Combustion Efficiency × C or N Content × Emission Ratio ($CH_4$-C or $N_2O$-N) × Mass Ratio ($CH_4$/C or $N_2O$/N) × GWP ÷ 1,000,000 (MT/($MMTCO_2E$)**

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,

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

**Adjustment Factor**

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

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