K-STATE Research and Extension

Department of Agronomy MF3119 Climate and Agriculture

Greenhouse Gases in Agriculture

Greenhouse gases influence climate. What are greenhouse gases, and what role do they play in agriculture?

Greenhouse gases allow solar radiation to reach the Earth's surface, while trapping thermal radiation leaving the Earth's surface.

The greenhouse gases most commonly associated with human activities include:

- Carbon dioxide (CO_2)
- Methane (CH_4)
- Nitrous oxide (N_2O)
- Hydrofluorocarbons, perfluorocarbons, and sulfur hexafluoride

Agriculture influences the atmospheric concentrations of the first three of these gases. The fourth category consists of human-made compounds specific to certain industries, and is not normally associated with agriculture or forestry, and they will not be discussed in this publication.

CO_2 Equivalents

By international convention, all greenhouse gas emissions are reported in terms of CO_2 equivalents. Each greenhouse gas is given a CO_2 equivalent or a value of Global Warming Potential (GWP). These values are based on the ability of a greenhouse gas to absorb heat in the atmosphere, relative to CO_2. Carbon dioxide is the baseline of this scale with a value of one. Methane has a value of 21, and N_2O has a value of 310 (Table 1). In other words, N_2O is 310 times more powerful than CO_2 at warming the atmosphere.

Greenhouse Gas Abundance

Of these greenhouse gases, CO_2 is the most abundant in the atmosphere. CO_2 is the primary greenhouse gas emitted by human activities in the United States, representing about 84 percent of total greenhouse gas emissions. The largest source of CO_2, and of overall greenhouse gas emissions, is fossil fuel combustion. Methane and CO_2 emissions in the United States have been decreasing slightly since 2007, while N_2O emissions have held mostly steady.

Agriculture's Role

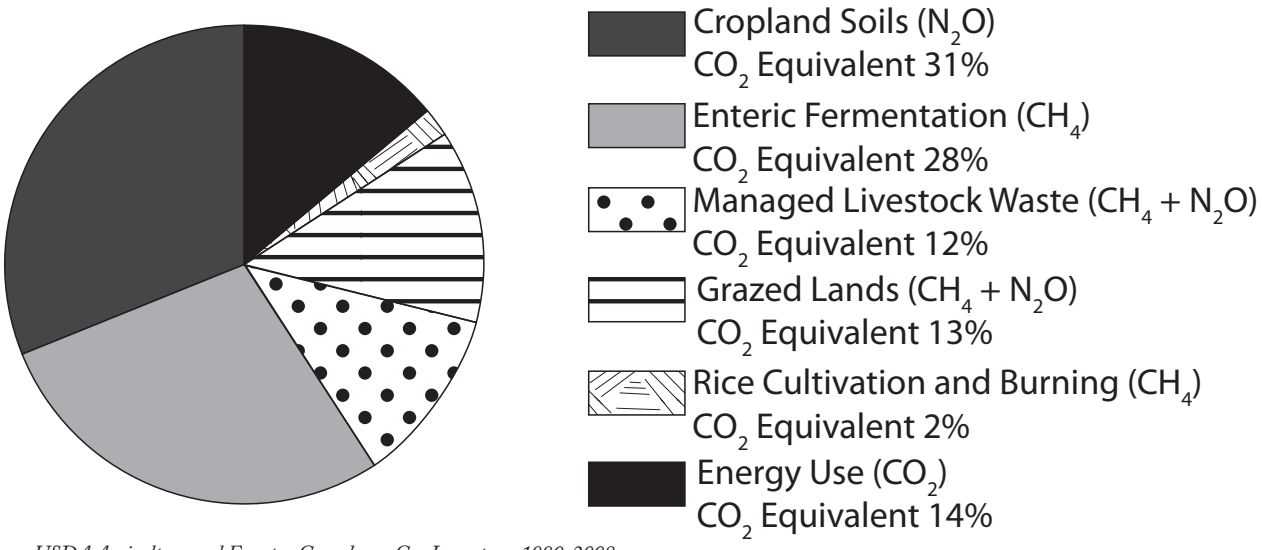
Agriculture can be both a source (Figure 1) and also can remove greenhouse gases from the atmosphere (Figure 2). Greenhouse gas emissions and reductions occur through many agricultural activities including fuel use, land use changes, tillage, fertilizer use, livestock production, manure management, and planting and destruction of forests.

Table 1. *Global Warming Potential, Atmospheric Life, and Anthropogenic Sources of Greenhouse Gases*

Greenhouse Gas	Global Warming Potential (100 year)	Approximate Atmospheric Life (years)	Sources Related to Human Activities
Carbon dioxide (CO_2)	1	50 to 200	Fossil fuel combustion Land use conversion Cement production
Methane (CH_4)	21	12	Fossil fuels Flooded rice paddies Landfill waste Livestock
Nitrous oxide (N_2O)	310	120	Nitrogen fertilizers Dry manure Combustion Industrial processes

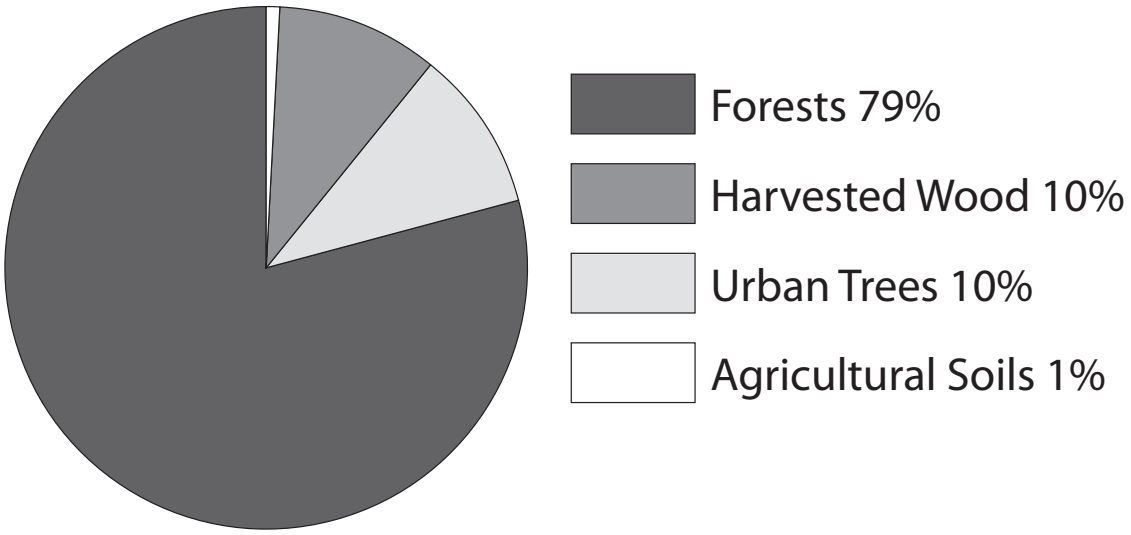
Source: Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2011 (February 2013) *www.epa.gov/climatechange/ghgemissions/usinventoryreport.html*

Figure 1. *Agricultural Sources of Greenhouse Gas Emissions in 2008*



Source: *USDA Agriculture and Forestry Greenhouse Gas Inventory: 1990-2008.*

Figure 2. *Agricultural Sinks of Carbon Dioxide in 2008*



Source: *USDA Agriculture and Forestry Greenhouse Gas Inventory: 1990-2008.*

The main emission sources in agriculture for each greenhouse gas are discussed in the following three sections.

Carbon Dioxide

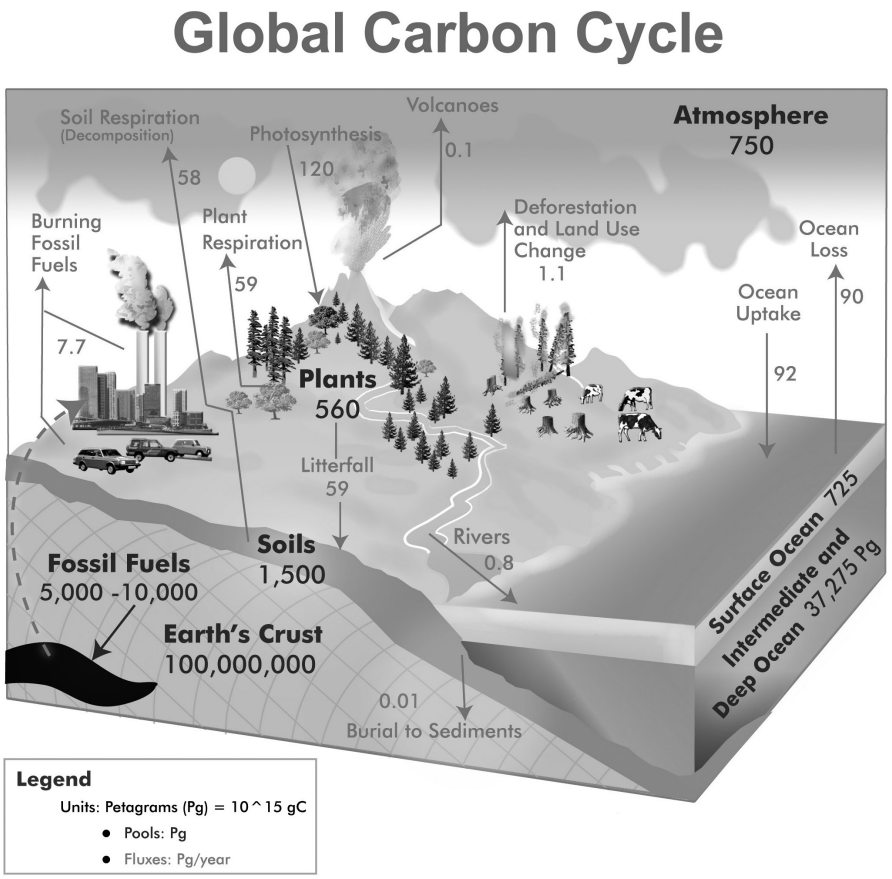
Carbon is a major component of almost every aspect of agriculture. All agricultural products are made of carbon, including food, feed, fiber, and even biofuels. Agricultural inputs such as fuel, fertilizer, and pesticides are also carbon compounds.

How Carbon Moves Through Agricultural Systems

Any discussion of activities that affect CO_2 emissions and sequestration in agriculture is based on an understanding of the carbon cycle and how atmospheric carbon is absorbed and released by plants and soils. In short, lower use of fossil fuels, greater plant production, and reduced soil disturbance lead to reduced CO_2 emissions and greater levels of soil carbon sequestration (the long-term storage of carbon in soils). That leads to a reduction in atmospheric CO_2 levels. On the other hand, greater fossil fuel usage, lower plant production, deforestation, and activities that cause loss of soil organic matter increase carbon emissions into the atmosphere.

Figure 3 provides one estimate of the global carbon balance. Different sources have slightly different numbers, but this estimate from the U.S. Geological Survey is one of the best available. The atmosphere contains a total of about 750 petagrams (or gigatons) of carbon.

Figure 3. *The global carbon cycle. The numbers in this graphic are in units of petagrams, or one trillion grams, of carbon.*



Source: *U.S. Geological Survey, geology.com/usgs/sequestration. (Copyright 2010 GLOBE Carbon Cycle Project, a collaborative project between the University of New Hampshire, Charles University and the GLOBE Program Office. Data Sources: adapted from Houghton, R.A. Balancing the Global Carbon Budget. Annu. Rev. Earth Planet. Sci. 007.35:313-347, updated emissions values are from the Global Carbon Project: Budget 2009.) Used with permission.*

A gigaton is one billion metric tons. This amount is dwarfed by the amount of carbon that exists on Earth in plant life, soils, fossil fuels, the Earth's crust, surface oceans, and intermediate and deep oceans. According to this NASA estimate, about 120 petagrams of carbon are absorbed out of the atmosphere by plant life and soils every year. In other words, about 16 percent of the carbon in the atmosphere is taken up by plant life and soils every year on a global basis.

CO_2 Emissions and Reductions in Agriculture

Agriculture as an industry is a source of CO_2 emissions, although not to the extent of other industries, such as electricity generation. The sources of CO_2 emissions in agriculture include fuel use, tillage, soil erosion, and the use of products that produce CO_2 during their manufacture, such as commercial nitrogen fertilizer.

Agriculture and land-use changes are also a major sink for CO_2 emissions reductions, which means that agriculture can decrease CO_2 from the atmosphere by storing or sequestering carbon in soils. CO_2 reductions are greater than the CO_2 emissions in agriculture; agriculture and forestry together act as a net sink for CO_2. That is, more carbon is stored in soils and tree growth every year than is released by activities in agricultural and forestry operations.

Table 2 illustrates this. The numbers in parentheses indicate a net reduction in atmospheric CO_2. Overall, agriculture, forestry, and other land-use changes sequester a net of about 1,075 Tg CO_2 equivalents (293 Tg C) per year in the United States. (A Tg, or teragram, is one million metric tons.) That compares to total greenhouse gas emissions in the United States of about 6,821 Tg CO_2 equivalents per year in the United States as of 2010, as reported by the U.S. EPA.

Methane

Methane (CH_4) is the second most abundant greenhouse gas in the earth's atmosphere.

How Methane Moves Through Agricultural Systems

Methane is a carbon-based compound, but has a significantly different pathway through the ecosystem

Table 2. *Net CO_2 Flux from Carbon Stock Changes in Land Use in U.S. (Tg C per year) Parentheses around a number indicate a negative (-) value.*

Sink category	1990	2005	2006	2007	2008	2009	2010
Forestland remaining forestland	(191.3)	(256.6)	(262.8)	(261.6)	(255.9)	(248.3)	(251.4)
Cropland remaining cropland	(8.0)	(5.0)	(5.2)	(5.4)	(4.9)	(4.7)	(4.3)
Land converted to cropland	0.6	1.6	1.6	1.6	1.6	1.6	1.6
Grassland remaining grassland	(14.2)	(2.4)	(2.4)	(2.3)	(2.3)	(2.3)	(2.3)
Land converted to grassland	(5.4)	(6.7)	(6.6)	(6.5)	(6.5)	(6.4)	(6.4)
Settlements remaining settlements	(15.6)	(23.9)	(24.5)	(25.1)	(25.6)	(26.2)	(26.7)
Other (landfilled yard trimmings and food scraps)	(6.6)	(3.2)	(3.0)	(3.0)	(3.0)	(3.05	(3.6)
Total	(240.5)	(296.2)	(302.8)	(302.2)	(296.6)	(289.8)	(293.1)

Note: 1 Tg = one million metric tons. Numbers in parentheses indicate sequestration or other removal of CO_2 from the atmosphere.

Source: U.S. EPA inventory of Greenhouse Gas Emissions and Sinks: 1990-2010, Table 7.2

www.epa.gov/climatechange/Downloads/ghgemissions/US-GHG-Inventory-2012-Main-Text.pdf

than CO_2. Methane is emitted from a variety of sources. Human-related activities that release methane include livestock production, rice cultivation, biomass burning, management of animal waste, and fossil fuel production. It is estimated by the United Nations' Intergovernmental Panel on Climate Change (IPCC) that 60 percent of global methane emissions are related to human-related activities.

Natural sources of methane include wetlands, gas hydrates (a crystalline solid on the ocean floor consisting of methane surrounded by water molecules), permafrost, termites, oceans, freshwater bodies, non-wetland soils, and other sources such as wildfires. Wetlands are especially conducive to the species of bacteria that produce methane during the decomposition of organic material.

Methane emission levels from a source can vary significantly from one country or region to another, depending on many factors such as climate, industrial and agricultural production characteristics, energy types and usage, and waste management practices. Methane has a short atmospheric life — about 12 years. Combined with its Global Warming Potential value of 21 (see Table 1.), this makes reducing methane emissions on a per-animal basis a good short-term greenhouse gas mitigation strategy.

Methane Emission Sources

Livestock digestive processes, livestock manure, and rice cultivation are the primary sources of methane in agriculture.

Livestock enteric fermentation. Cattle, sheep, goats, and other ruminant animals produce significant amounts of methane as part of their normal digestive processes. In the rumen of these animals, microbial (or enteric) fermentation produces methane as a by-product, which can be emitted by the animal.

Livestock manure management. Anaerobic (in the absence of oxygen) decomposition of livestock wastes produces significant amounts of methane. Liquid manure management systems, such as lagoons and holding tanks, can be a source of methane emissions. Dry manure is typically an insignificant source of methane emissions.

Rice cultivation. Methane is produced during flooded rice cultivation by the anaerobic decomposition of organic matter in the soil. Flooded soils are ideal environments for methane production because of their high levels of organic materials and anaerobic conditions.

Methane Sinks

There are no CH_4 sinks in agriculture or forestry. However, operators can implement practices that reduce emissions.

Activities in Agriculture and Forestry that Affect Methane Emissions

Agricultural and forestry activities that affect methane emissions include:

- Animal production (beef and dairy cattle, sheep, goats), through enteric fermentation.
- Manure management, through the action of anaerobic decomposition of manure.
- Rice production, under anaerobic conditions.
- Burning of crop residues, normally only a minor source of methane.
- Forest fires. Both prescribed burns and unplanned fires can release methane.
- Water management in rice, organic, and aquic soils.

Nitrous Oxide

Nitrous oxide (N_2O), the third most abundant greenhouse gas, is closely tied to production agriculture.

How Nitrogen Moves Through Agricultural and Forestry Systems

Nitrogen naturally enters the soil through the activities of nitrogen-fixing bacteria (and blue-green algae), the deposition of animal wastes, or as the result of lightning and rainfall. Nitrogen also enters the soil as a result of human activities, such as the application of nitrogen fertilizers.

Within the soil, nitrogen undergoes many changes, such as through the microbial actions of nitrification and denitrification. Nitrification is the process of converting ammonium (NH_4) to nitrate (NO_3) in a well-aerated soil. Denitrification is the process of converting nitrate to nitrogen gas (N_2), which occurs under anaerobic conditions. Nitrous oxide is an intermediate product of both processes.

A small amount of nitrogen returns to the atmosphere as N_2O emissions when crop residues are burned. With large forest fires or where slash-and-burn methods are used on forestlands, N_2O emissions can be significant.

Nitrous Oxide Emission Sources

Nitrous oxide emissions vary greatly from region to region, depending on agricultural production and waste management practices, climate, soil type, and transportation factors. Areas of the country that use the most nitrogen fertilizer on cropland typically produce more nitrous oxide emissions than other areas.

In animal operations, N_2O is produced as part of the nitrogen cycle through the nitrification and denitrification of the organic nitrogen in manure and urine. Nitrous oxide emissions are most likely to occur in dry manure handling systems that have aerobic (in the presence of oxygen) conditions, but that also contain pockets of anaerobic conditions due to saturation.

Agricultural activities consistently account for more than 70 percent of N_2O emissions in the United States and forestry accounts for a small amount of N_2O emissions.

Nitrous Oxide Sinks

There are no N_2O sinks in agriculture and forestry. Operators can, however, implement practices that reduce emissions. For example, producers should make sure they do not use excessive rates of nitrogen for the crop being produced, use soil tests to determine available nitrogen levels, use proper timing and methods of nitrogen applications to match the needs of the crops, and use nitrification inhibitors or controlled-release nitrogen fertilizers when possible.

Activities in Agriculture and Forestry that Affect Nitrous Oxide Emissions

The types of activities that can cause N_2O emissions from agricultural and forestry operations include:

- **Nitrogen fertilizer use:** The rate, timing, and placement of nitrogen fertilizer applications are especially important.
- **Manure use:** The rate and timing of manure applications are especially important.
- **Production of nitrogen-fixing legumes:** All nitrogen, even nitrogen manufactured naturally by nitrogen-fixing legumes, is a potential source of nitrous oxide as the nitrogen undergoes the natural processes of nitrification and denitrification in the soil.
- **Tillage:** Tillage promotes the aerobic process of nitrification in the soil, which releases nitrous oxide.
- **Manure storage:** Nitrous oxide emissions are most likely to occur in dry manure handling systems that have aerobic (in the presence of oxygen) conditions, but that also contain pockets of anaerobic (in the absence of oxygen) conditions due to saturation.
- **Burning of crop residues:** This is typically a minor source of nitrous oxide emissions.

Greenhouse Gases: Glossary of Terms Used in Agriculture and Forestry

Afforestation: Planting forests on land that has not contained forests for at least 50 years.

Agroforestry: An integration of forest and cropping systems in areas where mutual benefits exist for feed, food, and fiber.

Anthropogenic: Actions resulting from human influence.

Anaerobic: The absence of oxygen.

Biofuels: Fuels produced from recently produced biomass. Examples include fuel-grade ethanol, butanol, and biodiesel.

Biochar: Charcoal used for particular purposes, especially as a soil amendment. Biochar is being looked at as a way to increase soil carbon sequestration. Biochar is a stable solid and rich in carbon. It can endure in soil for thousands of years.

Chemical Formulas of Common Greenhouse Gases

CH_4 — Methane

CO_2 — Carbon Dioxide

N_2O — Nitrous Oxide

Biomass: The total mass of living or recently dead biological material in a given biosystem.

Cap-and-trade: A mechanism of reducing overall greenhouse gas emissions (usually CO_2) in which a cap is set on how much greenhouse gases any given entity can emit. To emit more than the cap allows, the entity is allowed to buy (or "trade") an emission allowance from another source that has reduced its emissions.

Carbon dioxide (CO_2): A naturally occurring compound that is integral for life functions on Earth, found in gaseous form at surface temperatures. All animals, plants, fungi, and microorganisms produce CO_2 during respiration. Plants use it during photosynthesis. Carbon dioxide is also generated as a natural by-product of the decomposition of organic matter and the combustion of fossil fuels or vegetative matter, among other chemical processes.

Carbon dioxide equivalent: A universal standard of measurement against which the effects of different greenhouse gases can be evaluated in a common framework of global warming potential. For example, 1 ton of methane has a carbon dioxide equivalent or global warming potential of 21, meaning that one ton of methane in the atmosphere has the same effect on climate change as 21 tons of CO_2.

Carbon sequestration: The removal from the atmosphere and secure storage of CO_2 in oceans, forest, soils, or geologic materials through physical, biological processes such as photosynthesis, or man-made processes such as deep injection into geologic formations.

Carbon sink: A reservoir for carbon dioxide removed from the atmosphere. Natural sinks include oceans; trees, plants, and other organisms that use photosynthesis to remove carbon from the atmosphere by incorporating it into biomass; soils that provide long-term storage of carbon as organic matter and humus; and rocks such as limestone.

Carbon trading: A market-based mechanism that mitigates the increase in atmospheric CO_2 and other greenhouse gases. It allows CO_2 emitters to offset these emissions by purchasing "credits" from individuals or organizations that sequester CO_2 or other greenhouse gases.

Climate: The statistically relevant aspects of the atmosphere-hydrosphere-land surface system that varies over time ranging from months to millions of years. The classical period for averaging climatic variables as defined by the World Meteorological Organization is 30 years. Climate also describes the longer-term statistical averages and measures of variability associated with daily weather.

Climate change: Any systematic shift in the long-term statistics of climate elements (such as temperature, rainfall, or winds) sustained over several decades or longer. This can include changes to both averages of these elements as well as measures of variability and extremes. These changes can be caused by natural external forcings (see definition for forcing(s) below), such as changes in solar emission or slow changes in the Earth's orbital elements; by natural internal processes of the climate system; or by human activities (anthropogenic forcings).

Conservation tillage: Methods of soil tillage that leave a minimum of 30 percent of crop residue on the soil surface or at least 1,000 pounds per acre of small grain residue on the surface during the critical soil erosion period.

Conventional tillage: Tillage systems that leave less than 15 percent crop residue cover or less than 500 pounds per acre of small grain residue. These systems often involve multiple operations with various implements such as a moldboard plow, disk, or chisel plow.

Cover crops: Grasses, legumes, brassicas, or small grains grown between regular cash crop growing seasons to reduce soil erosion, improve soil organic matter, and conserve soil moisture by increasing the amount of residue on the soil surface.

Denitrification: The anaerobic microbial process of transforming nitrate (NO_3^-) into nitrogen gas (N_2), and other compounds.

Fermentation: A biochemical process in which carbohydrates are converted to either an acid or an alcohol. Fermentation is used to produce ethanol for fuel.

Forcing(s): An agent that causes a change in a system, such as a climate system. A volcanic eruption is an example of an external forcing that can change the composition of the atmosphere. See also ***Radiative forcing***.

Forest carbon sequestration: The storage of atmospheric carbon in the biomass of trees, through the process of photosynthesis.

Global warming potential (GWP): The global warming potential of a given greenhouse gas describes its effect on climate change relative to a similar amount of carbon dioxide and can be presented in time horizons of 20, 100, and 500 years. As the base unit, carbon dioxide is assigned a global warming potential of 1.0 across each time horizon.

Greenhouse gases (GHG): Gases in the atmosphere that absorb and re-emit longwave (typically infrared) radiation from the Earth (trapping heat). There are three principal greenhouse gases of concern for agriculture: carbon dioxide (CO_2), nitrous oxide (N_2O), and methane (CH_4).

Humus: The more or less stable fraction of the organic matter remaining after the major portions of added plant and animal residues have decomposed. It is usually dark color.

Methane (CH_4): The principal component of natural gas that is associated with all hydrocarbon fuels. It is an important greenhouse gas with a global warming potential approximately 21 times higher than CO_2 (on a 100-year timeframe). Methane emissions are generated by the decomposition or conversion of carbon compounds in the absence of oxygen (i.e., anaerobic conditions), such as in landfills, peat bogs, the intestines (especially of ruminants), or in an anaerobic lagoon or digester.

Nitrification: The biological oxidation of ammonia (NH_4^+) to nitrate (NO_3^-) by nitrifying bacteria in aerobic conditions in soils and manures. The nitrification process is a part of the nitrogen cycle.

Nitrous oxide (N_2O): Nitrous oxide is generated as an intermediate product in the nitrification and denitrification processes in soils and manures. It has approximately 310 times more global warming potential than CO_2 (on a 100-year timeframe).

No-till: Planting crops without disturbing the ground with implements for seedbed preparation. Planting is done into existing residues, cover crops, or sod, and with no subsequent tillage operations.

Radiative forcing: A change in average net radiation at the top of the troposphere because of a change in either incoming solar or exiting infrared radiation. A positive radiative forcing tends on average to warm the Earth's surface; a negative radiative forcing on average tends to cool the Earth's surface. Greenhouse gases, when emitted into the atmosphere, trap infrared energy radiated from the Earth's surface and therefore tend to produce positive radiative forcing. See also *Greenhouse gases*.

Reduced tillage: Tillage systems that leave between 15 and 30 percent residue cover on the soil or 500 to 1,000 pounds per acre of small grain residue during the critical erosion period. This may involve the use of a chisel plow, field cultivators, or other implements.

Reforestation: The planting of trees on land that has recently been in trees.

Soil carbon sequestration: The stable storage of carbon in the organic matter of soils, ultimately through the capture of atmospheric carbon by the process of photosynthesis in plants and the eventual

decay and transformation of plant and animal life into stable organic compounds.

Soil organic matter: The organic fraction of the soil that includes plant and animal residues at various stages of decomposition; cells and tissues of soil organisms; and substances synthesized by the soil microbial and animal population. Commonly determined as the amount of organic material contained in a soil sample after passing through a 2-millimeter sieve.

Strip-till: A minimum tillage system in which a narrow strip of soil is tilled to prepare the seed bed for planting, while the row middles remain undisturbed.

For more information about greenhouse gases, carbon, climate, and agriculture, see *Top 10 Questions about Carbon and CO_2 in Agriculture*, MF3120. This and other publications are available at *www.ksre.ksu.edu.*

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