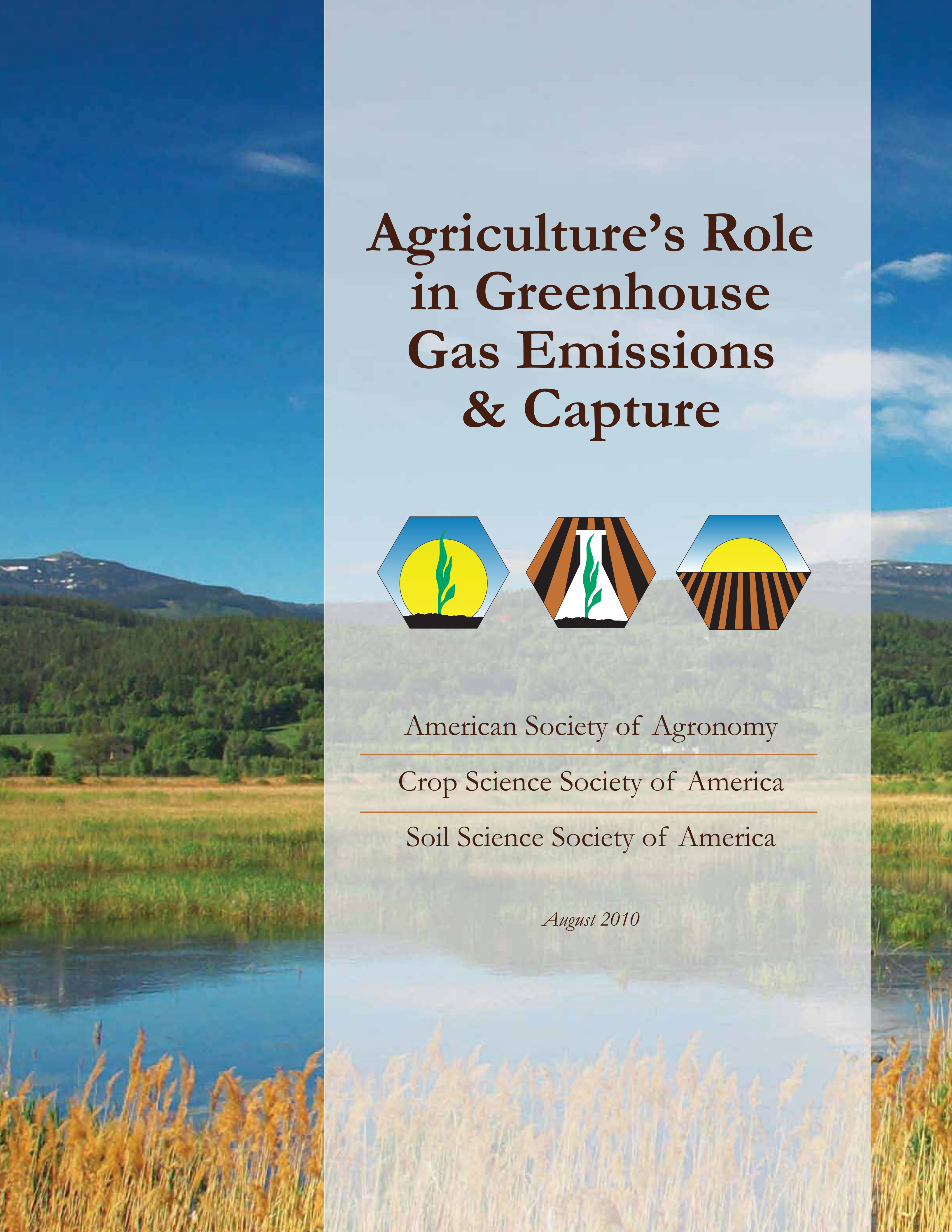

Agriculture's Role in Greenhouse Gas Emissions & Capture

American Society of Agronomy

Crop Science Society of America

Soil Science Society of America

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The **American Society of Agronomy (ASA)** is an international scientific society, founded in 1907, with 8,000+ members who work to advance the disciplines and practices of agronomy by supporting professional growth. ASA members include scientists, graduate and undergraduate students, and practitioners who are experts in land management, agroclimatology, education and extension, environmental quality, international agronomy, and integrated systems.

The **Crop Science Society of America (CSSA)**, founded in 1955, is an international scientific society comprised of 6,000+ members with its headquarters in Madison, WI. Members advance the discipline of crop science by acquiring and disseminating information about crop breeding and genetics; crop physiology; crop ecology, management, and quality; seed physiology, production, and technology; turfgrass science; forage and grazinglands; genomics, molecular genetics, and biotechnology; and biomedical and enhanced plants.

The **Soil Science Society of America (SSSA)** is a progressive, international scientific society that fosters the transfer of knowledge and practices to sustain global soils. Based in Madison, WI, and founded in 1936, SSSA is the professional home for 6,000+ members dedicated to advancing the field of soil science, providing information about soils in relation to crop production, environmental quality, ecosystem sustainability, bioremediation, waste management, recycling, and wise land use.

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AGRICULTURE'S ROLE IN GREENHOUSE GAS EMISSIONS AND CAPTURE

American Society of Agronomy
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INTERPRETIVE SUMMARY

Approximately 6% of all greenhouse gas (GHG) emissions originating in the United States (U.S.) come from agricultural activities.[1] These gases are in the form of carbon dioxide (CO_2), nitrous oxide (N_2O), and methane (CH_4). However, by employing proper management techniques, agricultural lands can both sequester carbon and reduce CO_2, CH_4, and N_2O emissions, thereby reducing their GHG footprint. Cap-and-trade climate change legislation, currently under discussion in the legislative and executive branches, may have broad and long-term implications for the agricultural sector. In order to determine the role of agriculture in GHG emissions and capture, a full life cycle accounting of GHG sources and sinks is needed.

The **American Society of Agronomy (ASA), Crop Science Society of America (CSSA), and Soil Science Society of America (SSSA)** have examined the evidence for GHG emissions and sequestration typical of agricultural systems in six U.S. regions *(Figure 1)*:

- Northeast
- Corn Belt
- Pacific
- Southeast
- Northern Great Plains
- Southern Great Plains

This report summarizes current knowledge of GHG emissions and capture as influenced by cropping system, tillage management, and nutrient source. Additionally, topics requiring further research have been identified.

Figure 1. Delineation of Geographic Regions for this Analysis

How is the Climate Changing?

Observations:

1. Global temperature rose 0.6 °C (1 °F) during the 20th century (*Figure 2*);[2]
2. Global temperature is projected to increase 2-6 °C (3.6-10.8 °F) during the 21st century.[3]

Rising global temperature can be attributed in part to increasing atmospheric concentrations of CO_2, CH_4, and N_2O, all important greenhouse gases that can be derived from agriculture and other anthropogenic activities. Over the past 200 years in particular, there has been a marked increase in temperature, with land-clearing and burning of fossil fuels contributing to this rise (*Figure 2*).

Global warming potential (GWP) is an estimate of the potential per molecule that a greenhouse gas (GHG) contributes to an increase in atmospheric temperature. The potential is based on a 100-year time period and scaled relative to a molecule of CO_2, which has a GWP of 1.

How Does Agriculture Contribute to Greenhouse Emissions?

American agriculture is responsible for about 6% of all U.S. GHG emissions,[1] which includes three—CO_2, CH_4, and N_2O—of the six major GHGs (the remaining are chlorofluorocarbons (CFCs), ozone (O_3), and water vapor (H_2O)).

Carbon Dioxide (CO_2) Emissions

The atmospheric concentration of CO_2 has risen nearly 25% in the past century (*Figure 3*). Carbon dioxide has a global warming potential (GWP) of 1 because it has the shortest atmospheric lifetime and lowest potential to absorb infrared radiation compared to other GHGs.

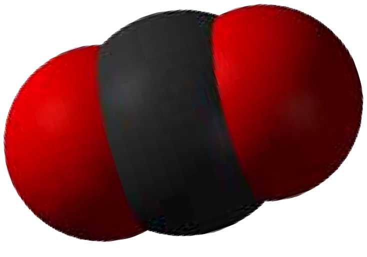


Figure 2. Reconstructions of six surface temperature variations (from Northern Hemisphere and global values) depicted with the instrumental record of global average surface temperature (in black). Range of uncertainty increases backward in time as indicated by shading. Reprinted with permission from Surface Temperature Reconstructions© (2006) by the National Academy of Sciences, Washington, D.C.[4]

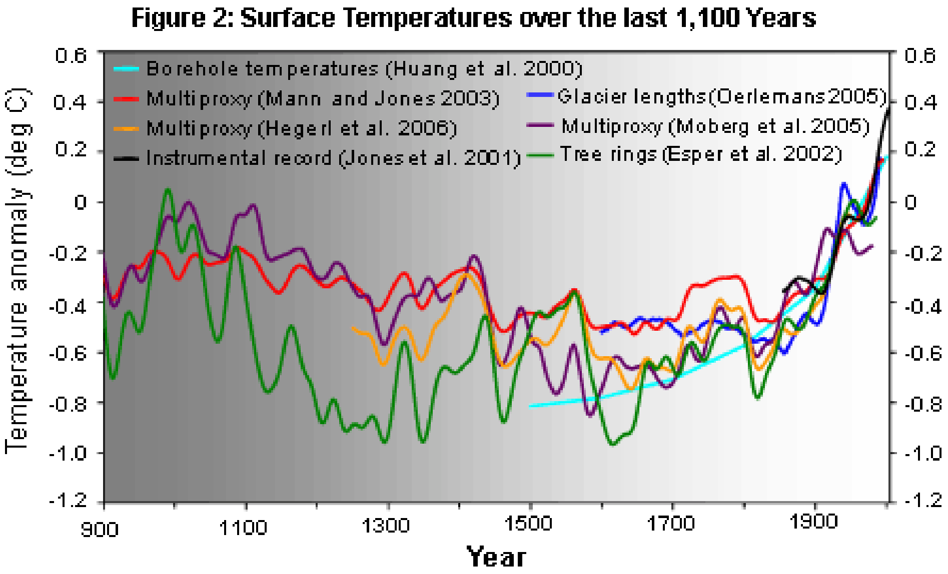
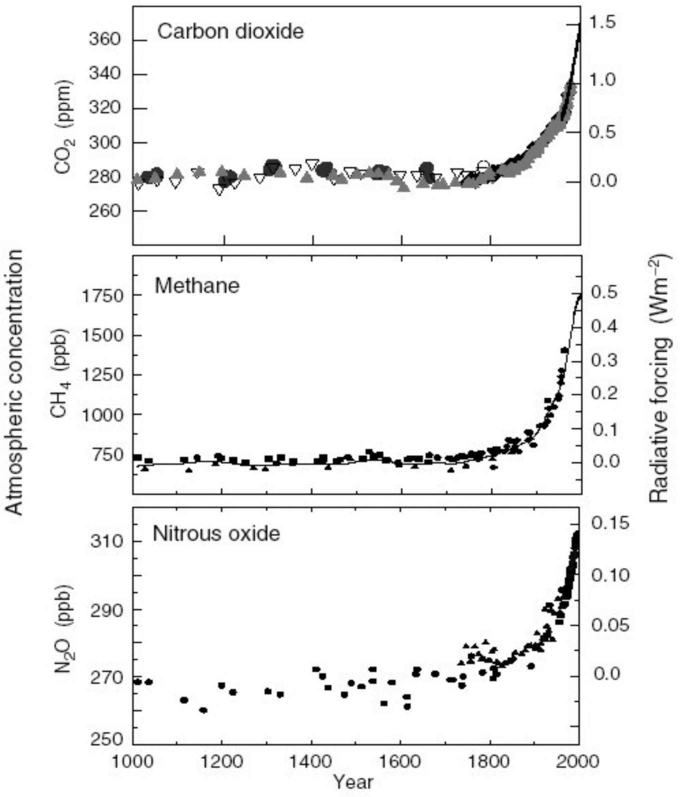


Figure 3. Atmospheric concentration of CO_2, CH_4, and N_2O during the past millennium.[2] Note the difference in radiative forcing of the three greenhouse gases, indicating the relative power to evoke change in the atmosphere.



Since the 1800s, two major sources have contributed to the rise in CO_2:

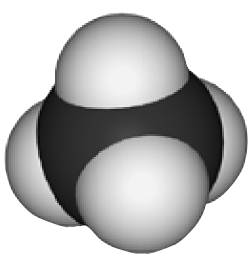
- Decomposition of soil organic matter (SOM) and plant biomass burning associated with the conversion of native vegetation—prairies and forests—to agriculture;[5] and
- Burning of fossil fuels.

The 2008 EPA data set, which is the most recent, indicates that energy related activities are responsible for 86% of total U.S. GHG emissions.[1]

In agriculture, burning of fossil fuel occurs with the manufacture and operation of farming equipment, fertilizer, and other agricultural inputs. Agricultural equipment uses fuel for plowing, planting, applying fertilizer and pesticides, and harvesting crops, as well as for processing and drying grains.

Methane (CH_4) Emissions

Methane is produced from a variety of sources, including natural gas and petroleum systems, landfills, enteric fermentation, and coal mining. While CH_4 is a long-lived GHG with a contemporary GWP 21 times greater than CO_2,[1] overall emissions are significantly lower than for CO_2. Energy-related activities contributed 34% of the CH_4 released in the U.S. in 2008.[1] Animal agriculture was responsible for an additional 25%, mainly due to emissions occurring in the intestines of ruminant animals.[1] Manure management and rice cultivation contributed 8 and 1%, respectively.

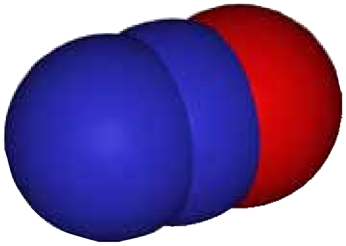


Emissions of CH_4 from agriculture are linked to bacterial processes in flooded soils under rice cultivation and from enteric fermentation that occurs in the digestive systems of ruminant livestock (cattle, sheep, goats, horses). Methane emissions also occur during decomposition of animal manure in uncovered lagoons and from crop residues under very wet field conditions.

Nitrous oxide (N_2O) Emissions

Nitrous oxide (N_2O) is a long-lived, potent GHG with 310 times the GWP per molecule of CO_2.[1] As with CH_4, N_2O emissions from agriculture are much lower than CO_2. However, the very large GWP makes N_2O a major contributor to climate change.

Emissions of N_2O in agriculture are predominantly from soils amended with nitrogen-rich amendments (fertilizers, manure, and compost), which release inorganic nitrogen (N) in the soil. Soil inorganic N is converted to N_2O by soil bacteria. On average, 1% of the N applied from fertilizers and organic amendments (manure, compost, and other organic fertilizers) and 2% of the N from the manure of grazing cattle,



buffalo, confined swine, and poultry is emitted into the atmosphere.[6] In general, N_2O emissions are directly related to the type, quantity, and method of application of fertilizer, but other factors such as soil type and weather patterns also influence emissions.[1]

HOW CAN AGRICULTURE MITIGATE GHG EMISSIONS?

Mechanisms for mitigating agricultural emissions include:

- Reducing fuel consumption;
- Enhancing soil carbon sequestration;
- Improving nitrogen-use efficiency (NUE);
- Increasing ruminant digestion efficiency; and
- Capturing gaseous emissions from manure and other wastes.

Reducing Fuel Consumption

Conservation tillage systems can reduce fuel consumption in cropland agriculture by decreasing the number of trips the tractor must make across the field. Conservation tillage also leaves crop residues on the soil surface to control erosion and build soil carbon. Further, conservation agricultural systems are effective at improving field surface properties and effectively reduce water runoff and soil erosion, ultimately improving local water quality.[7] Additional incentives and educational programs are needed for land managers to continue to adopt conservation agricultural systems.

Other options to reduce fuel consumption include:

- Harvesting forage by livestock grazing rather than mechanically;
- Designing grain cropping systems to allow full drying of crops in the field prior to harvest;
- Reducing the amount of water pumped for irrigation;

UNDERSTANDING HUMUS & SOIL CARBON

What is Humus?

Humus is stabilized organic matter in soil and is:

- 58% carbon;[8]
- complex in molecular structure; and
- both water absorbing and water resistant.

These characteristics limit the ability of microbes to break humus down into CO_2.

Co-Benefits of Soil Carbon *On* the Farm:

- builds soil fertility;
- increases water infiltration;
- protects soil from compaction by enhancing soil structure; and
- provides micro-environments to encourage soil biodiversity.

Co-Benefits of Soil Carbon *Off* the Farm:

- filters water to protect streams, lakes, and rivers from nutrient and pathogen runoff from agricultural fields; and
- enhances wildlife habitat.

NITROGEN FERTILIZER

Applying 100 lbs. of nitrogen fertilizer per acre—a common application rate—will result in the emission of about 2 lbs. of N_2O. [3]

CONSERVATION TILLAGE

- direct drilling;
- no-tillage;
- strip tillage; and
- ridge tillage.

- Employing nutrient management strategies to continually adjust fertilizer application rates for efficient, sustainable production; and
- Using legume-based rotations or organic agricultural systems to reduce N fertilizer applications.

Enhancing Soil Carbon Sequestration

Crops remove CO_2 from the atmosphere during photosynthesis *(Figure 4)*. Soil carbon sequestration is the transformation of crop residues and roots into long-lived carbon compounds in the soil through the process of microbial decomposition.[9]

Because of its persistence, soil organic matter (soil carbon) is a key pathway to offset agricultural GHG emissions.

Conservation agricultural practices promote soil carbon sequestration by:

- Increasing the time and amount of crop residues left on the soil surface; and
- Reducing soil disturbance, thereby decreasing CO_2 emissions.

In some areas, conservation tillage, combined with intensive crop rotations that include cover crops, can save farmers irrigation water and fuel, while sequestering an average of 1,700 lbs. of CO_2 (464 lbs. C) per acre each year.[10] Conservation tillage alone may sequester around 900 lbs. of CO_2 per acre each year. Additionally, well-aerated soils with high surface organic matter can consume CH_4 from the atmosphere.

Conservation agricultural practices include:

- Conservation tillage;
- Winter cover crops;
- Crop residue and waste management;
- Diverse crop rotations;
- Perennial pastures; and
- Land idling programs (e.g., Conservation Reserve Program).

Improving Nitrogen-Use Efficiency

The most effective method for reducing N_2O emissions is to increase nitrogen-use efficiency (NUE) by applying precise amounts of nitrogenous fertilizer or manure to crops based on N estimates from soil and plant tissues tests. Precisely timing N fertilizer applications will also increase NUE, ultimately leaving less N in the soil available for microbes to break down and release as N_2O. Accurate timing will also reduce fertilizer N losses due to nitrate (NO_3) leaching.

Adoption of the following practices will increase NUE:

- Soil nitrate tests prior to N fertilizer applications can provide land managers with a timely understanding of actual crop need;

- Precisely timing fertilizer application to match the period of time when plants need nutrients;
- Using adaptive management approaches to monitor plant health will help reduce N_2O emissions;
- Geographic information systems (GIS) can be used in combination with variable-rate technology, crop monitoring, and other technologies to apply N fertilizers based on crop need;
- Leguminous green manures can convert nitrogen gas from the atmosphere to plant-available N for crop use;
- Winter cover crops can remove excess soil N remaining after the harvest of summer crops; and
- Filter strips near streams can intercept N, using it for biomass production and wildlife habitat, as well as keeping it from entering aquatic systems and transforming into N_2O.

Increasing Ruminant Digestion Efficiency and Minimizing CH_4 Emissions from Rice

Methane emissions from agriculture can be decreased by reducing emissions from ruminant livestock, animal waste, and rice cultivation. Livestock related CH_4 emissions can be mitigated by:

- Adjusting the portions of animal feed to decrease digestion time;
- Using edible oils or other feed additives to reduce metabolic activity of rumen bacteria that produce CH_4;
- Capturing CH_4 emissions from livestock waste using covered lagoons and converting to electricity; and
- Applying manure to the soil as a nutrient source rather than storing it as waste.

Emissions of CH_4 from rice cultivation can be minimized by:

- Introducing more efficient water and fertilizer management; and
- Growing rice cultivars that inhibit CH_4 production.

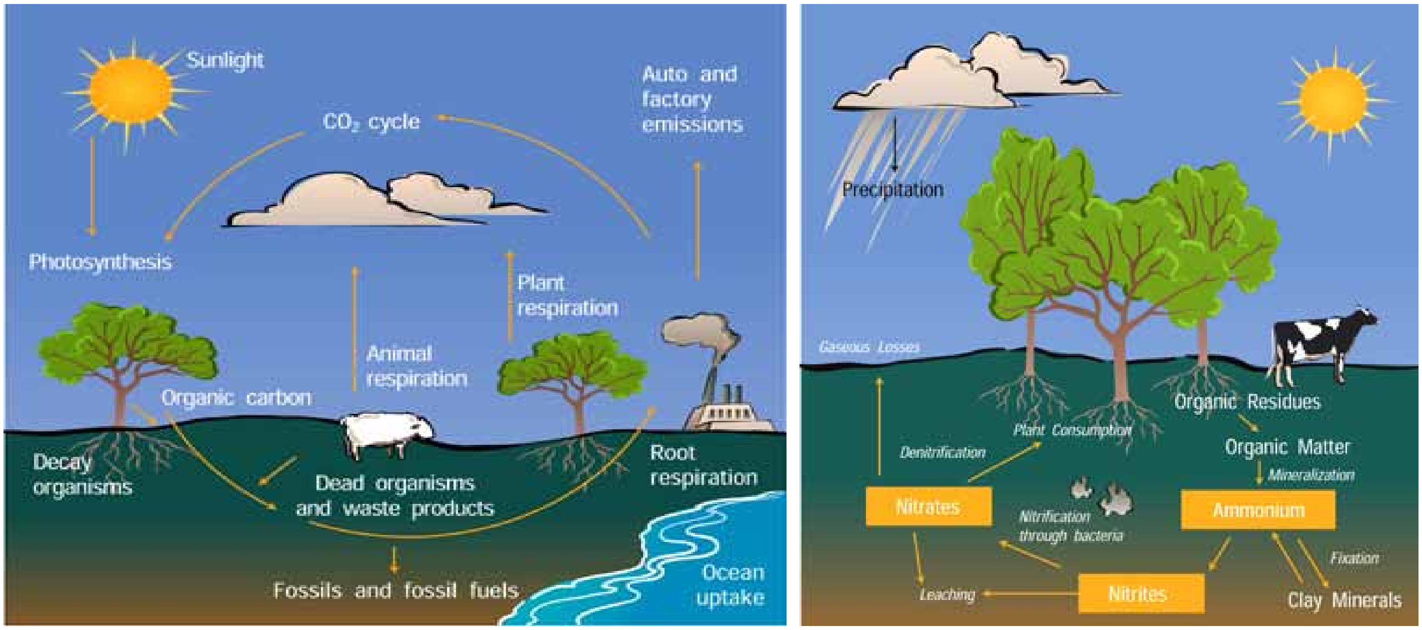


Figure 4. Carbon and Nitrogen Cycles (Copyright: University Corporation for Atmospheric Research)

WHAT ARE THE GHG CONTRIBUTIONS OF MAJOR U.S. CROPS?

Greenhouse gas (GHG) emissions from agricultural systems are directly affected by management practice and cropping system. A national management strategy or plan is needed to reflect region-specific soil types and climatic conditions (temperature, precipitation, and wind).

Methods

- ✓ An initial effort to identify regionally-appropriate conservation agricultural practices to promote soil carbon sequestration and mitigate emissions of CO_2, CH_4, and N_2O has been developed from both:
  - Direct field measurements; and
  - Model simulations (e.g., *Century Model*,[11] Version 5).
- ✓ Emissions data were organized according to the predominant cropping system in six geographic regions—Northeast, Southeast, Corn Belt, Northern Great Plains, Southern Great Plains, and Pacific (*Figure 1*).
- ✓ Cropping systems were classified by crop species, typical rotation, tillage type, nutrient source, and irrigation usage. Greenhouse gas emissions associated with the production of N fertilizer and use of farm machinery were included.

Results

- Overall, the data indicate that no-tillage or reduced tillage management results in lower emissions of CO_2, not only from soil, but also from farm machinery due to a reduction in the number of tractor passes.
- Crop rotations that include soybean, a nitrogen-fixing legume, have lower N_2O emissions because less N fertilizer is required.
- Field measurements of GHG emissions were generally not available for cropping systems in most regions; as a result, estimates generated from the *Century Model* were reported.

Findings

- Rigorous field validation (measurement) of the modeled data is urgently needed.
- Without model validation using data collected in the field, it will not be possible to fully account for and quantify GHG emissions and capture.
- Without such measurements, crop advisers and other consultants will be compromised in their ability to counsel land managers on the best methods to mitigate GHG emissions.

Annual Crops

Production of biofuel feedstocks with annual crops has the same GHG footprint as annual cropping systems grown for food, with one important additional consideration–crop residues.

- If crop residues are removed from the field for biofuel production rather than left in place to build soil carbon, soil carbon sequestration will be reduced, thereby increasing the GHG footprint of the biofuel.

Perennial Crops

Perennial crops grown for biofuels have a small GHG footprint, because they are not tilled once established. As a result, soil carbon accumulates as root biomass and as soil organic matter. Perennial crops also have high NUE—even when fertilized they leave relatively little nitrogen in the soil for N_2O emission or nitrate (NO_3) leaching.

Biofuel Production

Biofuel production of perennial feedstocks on land that requires clearing or draining will increase the GHG footprint, because clearing and draining increase CO_2 and N_2O emissions.

HOW CAN AGRICULTURE ENHANCE SOIL CARBON SEQUESTRATION AND REDUCE GHG EMISSIONS?

Although soil carbon sequestration and GHG emissions from agriculture have been investigated for several decades, many geographic regions have insufficient data to make realistic localized estimates about emissions from agricultural systems.
The ASA, CSSA, and SSSA find that additional research on soil carbon sequestration and GHG (CO_2, CH_4, and N_2O) emission reduction is needed in conservation agricultural systems across the U.S. Futhermore, development of a standardized methodology for measuring soil carbon, CH_4, and N_2O fluctuations is essential for uniformity so that estimates from around the country (and world) can be compared.

National Research Gaps

Long-term field experiments and rigorous data collection and processing are needed for the U.S.'s diverse agricultural systems, especially for irrigated cropping systems, to validate simulation models. Full life cycle analyses that include CO_2, CH_4, and N_2O emissions need to be conducted in each region to better understand:

- How to best integrate crop and animal production systems to achieve better crop productivity, soil carbon sequestration, and reduce GHG emissions;
- Changes in depth distribution of soil organic carbon over extended periods of time and impacts on permanence;[†]
- Influence of regional conservation agricultural systems on soil carbon dynamics; and
- Benefits of soil carbon on biodiversity, water quality, soil fertility, etc.

Such investigations may reveal new income streams for farmers, while also generating information on new sustainable agriculture production practices.

Regional Research Gaps

- **Northeast:** This region has very few studies in general. Many more studies are needed to quantify GHG emissions in conservation agricultural systems.
- **Southeast:** The Southeast needs long-term field experiments and rigorous data collection for irrigated cropping systems to validate simulation model results. Full life cycle analyses of major crop (cotton, peanut, sugarcane) and animal (beef, dairy, poultry, swine) production systems are also needed. Finally, further research needs to be conducted on integrated crop-livestock systems to allow us to understand how to best improve air, soil, and water quality.
- **Corn Belt:** There are very few field studies for this region. There is a need for long-term estimates of agricultural GHG emissions over multiple, consecutive years and the development of conservation agricultural management practices to accommodate common agricultural systems.
- **Northern Great Plains:** Again, there are few field studies on CO_2, CH_4 and N_2O emissions from agriculture for this region. Full life cycle analyses of dryland agricultural production systems are sorely needed.
- **Southern Great Plains:** Research is needed to understand the interactions of irrigation, tillage, and crop rotations in controlling GHG emissions for this region.
- **Pacific:** There is a need for improved long-term studies of agricultural GHG emissions and the development of conservation agricultural management practices to accommodate the many types of agriculture.

[†] According to the Environmental Protection Agency, "permanence" in agriculture and forestry refers to the potential for carbon sequestered to be not partially or completely reversible.

Revisiting Conservation Agricultural Practices

Agricultural practices that promote good stewardship of the land will reduce GHG emissions and maximize soil carbon sequestration. The conservation agricultural practices listed here can limit soil erosion and increase soil organic carbon and include: conservation tillage, cover cropping, diverse crop rotations, and improved pasture management. However, for the future, in order to minimize agriculture's impact on the environment while maximizing farmers' income, we recommend federal programs that:

- Encourage the development of conservation agricultural systems to: (1) sequester CO_2 as soil organic carbon, (2) enhance CH_4 consumption, and (3) reduce N_2O emissions;
- Encourage planting of cover crops and leguminous green manures to enhance soil carbon sequestration and increase NUE (and discourage bare fallow as a land-use option);
- Encourage diversified crop rotations, including perennial vegetation whenever possible, to enhance NUE;
- Discourage excessive use of N fertilizer and provide incentives for producers to increase NUE;
- Discourage row-crop production and use of N fertilizer on land directly adjacent to wetlands and streams, since N additions to N rich soils will impair water quality and increase N_2O emissions; and
- Encourage approaches to apply soil amendments in the right form, quantity, place, and time.

Improved NUE can be achieved by using split-application rates, slow-release technologies, and other methods to precisely meet the needs of the plant, while reducing ancillary N_2O emissions. Animal agriculture is an important contributor of GHG emissions; however manipulating animal diets and handling manure appropriately can significantly reduce CH_4 and N_2O emissions with minimal effort and cost.

Managing Current Policy

Conservation programs and ecosystem markets should be integrated and linked to agroecosystem management. **Policies are needed that support the most appropriate agricultural land management practices for reducing GHG emissions.** Furthermore, the agricultural sector should be encouraged to employ strategies to curb fossil fuel use.

Agriculture has the potential to reduce its environmental footprint and offset GHG emissions. Burning of fossil fuel by the general population is, by far, the greatest source of GHG emissions. By developing sustainable alternatives to fossil fuels and reducing our energy demand, we may stabilize GHG emissions and minimize anticipated global climate change. With rigorous federally supported research, education, and extension programs, in tandem with industry support, conservation agricultural systems can help reduce GHG emissions and enhance soil carbon sequestration.

REGIONAL CHARACTERISTICS

(See Figure 1)

Northeast

Crops grown in this region are primarily corn and soybean rotations for dairy feed.

- **Climate:** A cold and wet region, with an average annual temperature of 43 °F and average rainfall of 36”.
- **Terrain:** Rocky soils with considerable slopes.
- **Amendments:** Inorganic fertilizer and manure.
- **Common Management:** Conventional tillage using moldboard plowing (complete inversion of soil).
- **Model Estimates:** Carbon in cultivated soil increased an average of 1,190 lbs. per acre CO_2 per year according to model estimates in fields managed with no-till.
- **Data:** Only a few studies to date have examined the effects of management on GHG emissions.

Southeast

The Southeast region is characterized by a diversity of crop and animal production systems, where the majority of U.S. cotton, peanut, rice, sweet potato, sugarcane, and tobacco commodities are produced. Corn, soybean, wheat, hay, silage, pasture, and small grains are also common. Animal manure produced from swine, poultry, and beef and dairy cattle operations could be more fully utilized as a source of plant nutrients if more uniformly distributed into cropping systems across the region.

- **Climate:** Hot summers and mild winters, with average annual temperature ranging from 50-75 °F and average precipitation ranging from 40-60".
- **Terrain:** Lowlands (Mississippi Valley, Coastal Plain), uplands (Piedmont), mountains (Appalachians).
- **Amendments:** Inorganic fertilizer and manure (poultry, swine, cattle).
- **Common Management:** Mainly conventional tillage cropland (adoption of conservation tillage has been slow) and continuous grazing of pastures.
- **Model Estimates:** Various pasture management approaches have been evaluated for their potential to sequester soil carbon in the region, demonstrating that pastures can sequester an average of 3,300 lbs. CO_2 per acre per year. While model estimates and field data show a high potential for increasing soil carbon with the use of best management practices in cropping systems, more observations are needed.
- **Data:** Few data have been collected on CO_2, CH_4, and N_2O emissions from agricultural operations in the region. Soil carbon sequestration estimates are still lacking for the many different soil types in the region, especially in rotations with peanuts and cotton.

Corn Belt

Typical rotations in the Corn Belt region include continuous corn and corn-soybean with a variety of management practices.

- **Climate:** Average annual temperature ranges from 41-56 °F and average precipitation 24-49", with a decrease in rainfall from east to west.
- **Terrain:** Emissions are higher in areas with significant seasonal soil freezing and thawing.
- **Amendments:** Inorganic fertilizer and manure.

- **Common Management:** Farmers are increasingly adopting conservation or no-till practices.
- **Model Estimates:** While models indicate an additional decrease in CO_2 emissions (221 lbs. CO_2 per acre per year) with no-tillage practices, additional field validation of models will help improve estimates.
- **Data:** Few field studies on CO_2, CH_4, and N_2O emissions have been conducted in this region, so estimates are not robust in terms of multiple years and a wide diversity of soils and agronomic management practices.

Northern Great Plains

Typical crops grown in this region include small grains (wheat, barley), oilseeds (sunflower, canola), and annual legumes (soybean, dry pea). Wheat-based cropping systems are predominant and fallow fields have become less common with greater adoption of no-till.

- **Climate:** Average annual temperature ranges from 40-55 °F and average precipitation ranges from 10-30".
- **Terrain:** Flat to rolling plains (east), mountainous (west).
- **Amendments:** Inorganic fertilizer and manure (cattle).
- **Common Management:** Conventional cropland management utilized in the eastern portion of region, whereas conservation and no-tillage employed in the west where precipitation is limiting. Rangeland extensively grazed at stocking rates proportional to biomass availability.
- **Model Estimates:** The *Century Model* estimates predict a decrease in emissions of approximately 300 lbs. CO_2 per acre per year in cropping systems managed with no-tillage as opposed to minimum tillage.
- **Data:** Few field studies have been conducted on CO_2, CH_4 and N_2O emissions and soil carbon sequestration, and fewer studies have been conducted on the mitigation capacity of best management practices to offset emissions in this region. Consequently, it is impossible to generate robust GHG estimates.

Southern Great Plains

Dryland cropping systems are the norm in this region, and include mainly small grains (wheat, barley, millet, sunflower) in which a winter wheat–summer fallow rotation has been the dominant cropping system. Irrigated crops include corn and alfalfa with cotton in the southern part of the region, as well as dry beans, vegetables, and specialty crops in some areas. The region has many large concentrated animal feeding operations (CAFOs) and faces challenges with livestock waste management and the accompanying problems of air, soil, and water quality and GHG emissions.

- **Climate:** A hot and dry region with an average annual temperature of 60 °F and average precipitation of 10".
- **Terrain:** Large areas of rangeland, but also substantial dryland cropping.
- **Common Management:** Irrigated cropland agriculture; no-till has increased over the past 20 years, but still represents less than 12% of total cropland.
- **Model Estimates:** Models show an increase in soil carbon sequestration with adoption of no-tillage in corn-wheat, continuous corn, continuous wheat, and soybean-corn cropping systems. In dryland cropping systems, adoption of no-till increases crop water-use efficiency, reducing the frequency of summer fallow. (This in turn increases soil carbon storage and reduces fuel consumption, resulting in lower GHG emissions.)
- **Data:** Need to find new cropping systems that can be successful with limited irrigation, in combination with reduced or no-till systems. Limited experimental data in the region suggest that no-till adoption on irrigated croplands may also help sequester carbon and reduce GHG emissions.[12] It is apparent that research on the interactions of irrigation, tillage, and crop rotations in controlling GHG emissions will be critical to make wise management decisions for this region.

Pacific

The main crops grown are wheat, corn, cotton, and rice.

- **Climate:** This agroecoregion is large and diverse ranging from desert to tundra. The climate zones can be described as: southwest Pacific region 39-120 °F, 6-12” of precipitation; mid-Pacific region 37-97 °F and 10-18” of precipitation; and the northwest Pacific region 21-88 °F and 6-22” of precipitation.
- **Terrain:** Rolling hill topography, with production mainly in valleys.
- **Amendments:** Inorganic fertilizer.
- **Common Management:** Conventional tillage using moldboard plowing.
- **Model Estimates:** No-till in this region will increase soil carbon but may not reduce N_2O emissions.
- **Data:** This region has significant crop diversity (>200 crops), while virtually no data exists on GHG emissions.




REFERENCES

1. U.S. Environmental Protection Agency. 2010. Inventory of U.S. greenhouse gas emissions and sinks: 1990-2008. EPA, Office of Atmospheric Programs (6207J), Washington, DC. Available online at http://epa.gov/climatechange/emissions/usinventoryreport.html (Accessed 18 May 2010; verified 18 May 2010).
2. IPCC. 2001. Climate change 2001: The scientific basis. Cambridge Univ. Press, Cambridge, UK. Available online at http://www.grida.no/publications/other/ipcc_tar/?src=/climate/ipcc_tar/wg1/index.htm (Accessed 21 June 2010; verified 21 June 2010).
3. IPCC, 2007: Summary for Policymakers. In: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M.Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA. Available online at: http://www.ipcc.ch/pdf/assessment-report/ar4/wg1/ar4-wg1-spm.pdf. (Accessed 24 June, 2010; Verified 21 July 2010).
4. National Research Council (NRC). 2006. Surface temperature reconstructions for the last 2,000 years. National Academy Press, Washington, DC.
5. Houghton, R.A., J.E. Hobbie, J.M. Mellilo, B. Moore, B.J. Peterson, G.R. Shaver, and G.M. Woodwell. 1983. Changes in the carbon content of terrestrial biota and soils between 1860 and 1980: A net release of CO_2 to the atmosphere. Ecol. Monogr. 53:235-262.
6. IPCC 2006. 2006 IPCC Guidelines for National Greenhouse Gas Inventories. Prepared by the National Greenhouse Gas Inventories Programme, Eggleston H.S., Buendia L., Miwa K., Ngara T. and Tanabe K. (eds). Published: IGES, Japan. Available online at http://www.ipcc-nggip.iges.or.jp/public/2006gl/vol4.html (Accessed 1 May 2008; verified 18 May 2010).
7. Franzluebbers, A.J. 2008. Linking soil and water quality in conservation agricultural systems. J. Integr. Biosci. 6(1):15-29.
8. Stevenson, F. 1982. Humus chemistry: Genesis, composition, and reactions. Wiley Interscience, New York.
9. Johnson, J.M.-F., A.J. Franzluebbers, S.Lachnicht-Weyers, and D.C. Reicosky. 2007. Agricultural opportunities to mitigate greenhouse gas emissions. Environ. Pollut. 150:107-124.
10. Franzluebbers, A.J. 2005. Soil organic carbon sequestration and agricultural greenhouse gas emissions in the southeastern USA. Soil Tillage Res. 83:120-147.
11. Metherell, A.K., L.A. Harding, C.V. Cole, and W.J. Parton. 1993. CENTURY Soil Organic Matter Model Environment. Agroecosystem version 4.0. Tech. doc., GPSR Tech. Rep. No. 4, USDA-ARS, Ft. Collins, CO.
12. Council for Agricultural Science and Technology (CAST). 2004. Climate change and greenhouse gas mitigation: Challenges and opportunities for agriculture. Task Force Rep. No. 141, CAST, Ames, IA, USA.

IPCC N_2O Emission Factor Summary

IPCC accounts for both direct and indirect emissions

Direct emissions:

- Include N_2O emitted from cropped and grazing land soils.
- 1% of the nitrogen (N) in synthetic and organic fertilizer amendments and unharvested crop residues (both above and below ground) is emitted into the atmosphere as N in the form of N_2O (N_2O-N).
- 1% of N released from mineralization of soil organic matter is emitted into the atmosphere as N_2O-N.
- 2% of N from waste deposited on pasture, range, and paddock lands by grazing cattle, buffalo, poultry and pigs is emitted into the atmosphere as N_2O-N.
- 1% of N from waste deposited on pasture, range, and paddock lands by sheep and other grazing animals not included above is emitted into the atmosphere as N_2O-N.

Indirect emissions:

- Emitted from N that left the farm and was converted to N_2O offsite.
- 1% of volatilized N is assumed to be converted to N_2O-N.
- 0.75% of nitrate (NO_3-) that leaches into water ways is assumed to be converted to N emitted in the form of N_2O.
- 10% of N in synthetic fertilizer is volatilized as N in the form of ammonia (NH_3) or NO_x.
- 20% of N in organic fertilizer and waste from grazing animals is volatilized as N in the form of NH_3 or NO_x.
- Assumes 30% of N leaches into waterways in the form of NO_3- from N in synthetic and organic fertilizers, animal waste, unharvested crop residues, and mineralized N.

Factors for Calculating N_2O-N

- Atomic weight (A_r) of N is 14
- A_r of O is 16
- A_r of C is 12
- To convert from N_2O-N to N_2O, multiply by $(14*2+16)/(14*2) \approx 1.6$
- To convert from N_2O to CO_2 equivalents, multiply N_2O by 310
- To convert from CO_2 eq. to CO_2-C, multiply by $(12)/(12+16*2) \approx 0.27$