

Abstract

Emissions of the three most important long-lived greenhouse gases (GHG) have increased measurably over the past two centuries. Carbon dioxide (CO₂), methane (CH₄), and nitrous oxide (N₂O) concentrations in the atmosphere have increased by approximately 35%, 155%, and 18%, respectively, since 1750. In the U.S., agriculture accounted for close to 7% of total GHG emissions (7260 Tg CO₂ eq.) in 2005. Livestock, poultry, and crop production contributed a total of 481 Tg CO₂ eq. to the atmosphere in 2005. This total includes an offset from agricultural soil carbon sequestration of roughly 32 Tg CO₂ eq. The primary agricultural sources are N₂O emissions from cropped and grazed soils (263 Tg CO₂ eq.), CH₄ emissions from enteric fermentation (112 Tg CO₂ eq.), and CH₄ emissions from managed livestock waste (41 Tg CO₂ eq.). Forests in the United States contributed a net reduction in atmospheric GHG of approximately 787 Tg CO₂ eq. in 2005, which offset total U.S. GHG emissions by approximately 11%. In aggregate, the U.S. agricultural sector (including GHG sources for crop, poultry, and livestock production and GHG removal from the atmosphere via sinks for in) was estimated to be a net sink of 306 Tg CO₂ eq. in 2005.

Keywords: climate change, greenhouse gas, land use, carbon stocks, carbon sequestration, enteric fermentation, livestock waste, nitrous oxide, methane, rice cultivation, energy consumption.

August 2008

Dear Reader:

I am pleased to present you with this report, *The U.S. Agriculture and Forestry Greenhouse Gas Inventory: 1990-2005*, an update to USDA Technical Bulletin 1907 (2004) which accounted for greenhouse gas emissions and sinks for the agricultural and forestry sectors through 2001.

This report is consistent with the Environmental Protection Agency's (EPA's) *Inventory of U.S. Greenhouse Gas Emissions and Sinks* (2007) in its assessment methods. However, EPA's national-scale reporting here has been disaggregated to provide a State-by-State presentation. We believe this format will serve as a useful resource to land managers, planners, and others with an interest in greenhouse gas dynamics and their relationships to land use and land use change.

Data collection and analysis, as well as coordination of this *Inventory*, could not have been accomplished without the contributions of Stephen Del Grosso, Ronald Follett, and USDA's Agricultural Research Service. I also express my thanks to Linda Heath and James Smith of the USDA Forest Service, James Duffield of USDA's Office of Energy Policy and New Uses, Stephen Ogle at the Natural Resources Ecology Laboratory of Colorado State University, and Tom Wirth in EPA's Office of Atmospheric Programs for their data, analysis, and review. Their thoughtful and diligent efforts compose the foundation of this report, which we hope will serve as a useful resource for a broad spectrum of land management-focused professionals and other interested individuals.

Sincerely,

William Hohenstein
Director, USDA Global Change Program Office

Contributors

Stephen Del Grosso (editor), Agricultural Research Service, USDA

Margaret Walsh (co-editor), Global Change Program Office, USDA

James Duffield, Office of Energy Policy and New Uses, USDA

Linda Heath, Forest Service, USDA

Stephen Ogle, Natural Resources Ecology Laboratory, Colorado State University

James Smith, Forest Service, USDA

Tom Wirth, Office of Atmospheric Programs, EPA

Table of Contents

	<u>Page</u>
List of Boxes, Maps, Tables, and Figures.....	vii
Acknowledgments	x
Glossary of Terms and Units	xi
Chapter 1: Introduction	1
1.1 Global Change and Global Greenhouse Gas Emissions in Agriculture and Forestry	1
1.2 Sources and Mechanisms for Greenhouse Gas Emissions	4
1.3 Strategies for Greenhouse Gas Mitigation.....	5
1.4 Purpose of this Report.....	6
1.5 Overview of the Report Structure	7
1.6 Summary of Changes and Additions for the 2nd Edition of the Inventory	8
Chapter 2: Livestock and Grazed Land Emissions.....	11
2.1 Summary of U.S. Greenhouse Gas Emissions from Livestock	11
2.2 Sources of Greenhouse Gas Emissions from Livestock	13
2.3 U.S. Livestock Populations.....	16
2.4 Enteric Fermentation.....	17
2.5 Managed Livestock Waste.....	21
2.6 Grazed Lands	26
2.7 Mitigating Greenhouse Gas Emissions from Livestock	30
Chapter 3: Cropland Agriculture	33
3.1 Summary of U.S. Greenhouse Gas Emissions from Cropland Agriculture.....	33
3.2 Sources of Greenhouse Gas Emissions in Cropland Agriculture	37
3.3 Nitrous Oxide Emissions from Cropped Soils.....	40
3.4 Methane Emissions from Rice Cultivation.....	49
3.5 Residue Burning.....	52
3.6 Carbon Stock Changes in Cropped Soils.....	57
3.7 Uncertainty in Estimating Carbon Stock Changes in Agricultural Soils.....	61
3.8 Mitigation of CO ² Emissions	62

Table of Contents

Chapter 4: Carbon Stocks & Stock Changes in U.S. Forests.....	65
4.1 Summary.....	65
4.2 Concepts and Conventions.....	69
4.3 Carbon Stocks and Stock Changes by Forest Type, Region, and Ownership	69
4.4 Mechanisms of Carbon Transfer.....	73
4.5 Methods.....	75
4.6 Major Changes Compared to Previous Inventories	78
4.7 Uncertainty.....	78
4.8 Planned Improvements.....	79
Chapter 5: Energy Use in Agriculture	81
5.1 Summary of Greenhouse Gas Emissions from Energy Use in Agriculture.....	81
5.2 Spatial and Temporal Trends in Greenhouse Gas Emissions from Energy Use in Agriculture	81
5.3 Sources of Greenhouse Gas Emissions from Energy Use on Agricultural Operations	82
5.4 Methods for Estimating Carbon Dioxide Emissions from Energy Use in Agriculture.....	84
5.5. Major Changes Compared to Previous Inventories	86
References.....	87
Appendix A.....	A-1
Appendix B	B-1
Appendix C	C-1

List of Boxes, Maps, Tables and Figures

Boxes

Box 1-1 Greenhouse Gas Emissions Units	2
--	---

Maps

Map 2-1 GHG Emissions from Livestock in 2005	13
Map 2-2 Methane Emissions from Enteric Fermentation in 2005.....	18
Map 2-3 GHG Emissions from Managed Livestock Waste in 2005	24
Map 2-4 Nitrous Oxide Emissions from Grazed Lands in 2005	27
Map 3-1 County Level Nitrous Oxide Emissions from Cropped Soils in 2005	35
Map 3-2 U.S. Cropped Land	37
Map 3-3 State Level Carbon Dioxide Fluxes from Cropped Soils in 2005	58
Map 4-1 Carbon Stock Change by State in 2005.....	65
Map 4-2 U.S. Forest Carbon Stocks in 2005	66
Map 4-3 Regions Used for Forest Stock Summaries.....	70
Map 5-1 Farm Energy Use by Region in 2005	81

Tables

Table 1-1 Agriculture and Forestry Greenhouse Gas Emission Estimates and Uncertainty Intervals, 2005.....	1
Table 1-2 Summary of Agriculture and Forestry Emissions and Offsets, 1990, 1998-2005.....	5
Table 2-1 Greenhouse Gas Emission Estimates and Uncertainty Intervals in 2005	11
Table 2-2 Greenhouse Gas Emissions by Livestock Category and Source in 2005.....	12
Table 2-3 Descriptions of Livestock Waste Deposition and Storage Pathways	14
Table 2-4 U.S. Methane Emissions from Enteric Fermentation in 1990, 1995-2005	18
Table 2-5 Greenhouse Gas Emissions from Managed Livestock Waste in 1990, 1995-2005	21
Table 2-6 Greenhouse Gas Emissions from Grazed Lands in 1990, 1995-2005	26
Table 3-1 Estimates and Uncertainties for Cropland Greenhouse Gas Emissions, 2005.....	33
Table 3-2 Summary of Greenhouse Gas Emissions from Cropland Agriculture, 1990, 1998-2005.....	34
Table 3-3 Nitrous Oxide Emissions from Differently Cropped Soils, 1990-2005	36

List of Boxes, Maps, Tables and Figures

Table 3-4 Methane from Rice Cultivation from Primary and Ratoon Operations by State, 1990-2005	50
Table 3-5 Change in Methane Emissions from Rice Cultivation, 1990-2005.....	51
Table 3-6 Greenhouse Gas Emissions from Agriculture Burning by Crop, 1990-2005	54
Table 3-7 Tillage Percentages by Management Category and Climate Zones.....	60
Table 3-8 Cropland Area by Management Practice.....	63
Table 4-1 Forest Carbon Stock Change Estimates and Uncertainty Intervals for 2005.....	65
Table 4-2 Carbon Stocks and Annual Change for Forest and Wood Pools, 1990, 1998-2005	67
Table 4-3 Forest Area, Carbon Stocks, and Net Annual Stock Change by Forest Type Group.....	68
Table 5-1 Definitions of Regions Used in Figure 5-2.....	83
Table 5-2 Energy Use and Carbon Dioxide Emissions by Fuel Source on U.S. Farms, 2005.....	85

Figures

Figure 1-1 Agricultural Sources of Greenhouse Gas Emissions in 2005.....	3
Figure 1-2 Agricultural Sinks of Carbon Dioxide in 2005.....	3
Figure 1-3 Agriculture and Forestry Emissions and Offsets for 1990, 1998-2005.....	4
Figure 2-1 Greenhouse Gas Emission from Livestock in 2005.....	12
Figure 2-2 Greenhouse Gas Emissions from Livestock Waste by Livestock Type in 2005	22
Figure 2-3 Greenhouse Gas Emissions from Managed Livestock Waste, 1990-2005.....	22
Figure 2-4 Estimated Reductions from Anaerobic Digesters, 1990-2005	31
Figure 3-1 U.S. Planted Cropland Area by Crop Type, 1990-2005	33
Figure 3-2 Annual Nitrogen Inputs to Cropland Soil	34
Figure 3-3 Methane from Rice Cultivation by State, 1990 & 2005.....	49
Figure 3-4 Greenhouse Gas Emissions from Field Burning by Crop Type, 2005.....	52
Figure 3-5 Change in Commodity Production, 1990-2005.....	53
Figure 3-6 Percent Change in Commodity Production, 1990-2005	53
Figure 3-7 CO ² Emissions and Sequestration from Cropland Soils, 2005.....	57
Figure 3-8 Future Carbon Dioxide Mitigation Potential; Adoption of Management Change by 50% of Farmers.....	63

List of Boxes, Maps, Tables and Figures

Figure 4-1(a) Forest Ecosystem Carbon Stocks; (b) Forest Ecosystem Average Stock Density	71
Figure 4-2 Net Annual Forest Carbon Stock Change.....	72
Figure 4-3 Summary Diagram of Forest Carbon Stocks and Carbon Transfer Among Stocks.....	75
Figure 5-1 Energy Use in Agriculture by Source, 1965-2005.....	82
Figure 5-2 Carbon Dioxide Emissions from Energy Use in Agriculture by Region in 2005.....	83
Figure 5-3 Carbon Dioxide Emissions from Energy Use in Agriculture by Fuel Source, 2001 & 2005.....	86

Acknowledgments

This report was made possible by contributions from a number of individuals and collaboration between the U.S. Department of Agriculture, the U.S. Environmental Protection Agency, and Colorado State University.

The U.S. Agriculture and Forestry Greenhouse Gas Inventory (USDA GHG Inventory) is supplemental to the official Inventory of U.S. Greenhouse Gas Emissions and Sinks (U.S. GHG Inventory) submitted by EPA to the United Nations Framework Convention on Climate Change each April. We thank the EPA for permission to reprint estimates and methodologies from the official U.S. GHG Inventory. We would like to acknowledge the contribution of Tom Wirth of EPA's Office of Atmospheric Programs, who provided detailed emissions data for livestock sources of methane and nitrous oxide reported in Chapter 2. Stephen Del Grosso and Sadie Skiles of USDA ARS NPA Soil Plant Nutrient unit in Fort Collins, CO, in collaboration with Stephen Ogle, William Parton, and Cindy Keough of Colorado State University, provided estimates for N₂O emissions from agricultural soils, wrote most of the text for Chapters 2 and 3, and all of the text for Chapter 1. The Natural Resources Ecology Laboratory (NREL) of Colorado State University prepared the agricultural soil carbon estimates and supporting text for Chapters 2 and 3. James Smith and Linda Heath of the USDA Forest Service, Northern Research Station, provided estimates and text for Chapter 4. The USDA Forest Service tailored their analysis for this report to partition regional and land ownership trends in forest carbon. James Duffield of the USDA Office of Energy Policy and New Uses prepared Chapter 5. The estimates presented in Chapter 5 are unique to this report and derive from ongoing work in the Office of Energy Policy and New Uses to track fuel consumption in agriculture. We acknowledge Mary F. Smith of USDA ARS NPA Soil Plant Nutrient unit for formatting the document for printing.

Comments provided by reviewers from the USDA ARS, EPA, USDA Forest Service, and Colorado State University greatly improved this document.

Glossary of Terms and Units

CO ₂	Carbon dioxide
CH ₄	Methane
N ₂ O	Nitrous oxide
NO _x	Nitrogen oxides
C	Carbon
GHG	Greenhouse gas
GWP	Global warming potential
Tg	Teragram (10 ¹² grams)
Tg CO ₂ eq.	Teragrams of carbon dioxide equivalent
Gg	Gigagram (10 ⁹ grams)
Mg	Megagram (10 ⁶ grams)
t	Metric ton (1,000 kg)
ha	Hectares
DE	Digestible energy (percent)
Y _m	Fraction of gross energy converted to CH ₄
TDN	Total digestible nutrients
VOCs	Volatile organic compounds
VS	Volatile solids
DM	Dry matter
Btu	British thermal unit
Qbtu	Quadrillion British thermal units
Tbtu	Trillion British thermal units
EF	Emission factor
MCF	Methane conversion factor