

Mitigating agricultural greenhouse gas emissions: A review of scientific information for food system planning

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Abstract

Agriculture contributes significantly to anthropogenic greenhouse gases (GHGs), with estimates of agriculture's contribution ranging from 10% to 25% of total global GHG emissions per year. The science regarding mitigating (reducing and removing) GHGs through agriculture is conflicting and inconclusive. However, the severity and urgency of climate change and its potential effects on food security demonstrate that we must include mitigation within food system planning frameworks. In British Columbia, Canada, the provincial

government has established significant GHG reduction targets for its agencies, and has called on local governments to reduce their carbon footprints through a charter and incentive, as well as through growth management legislation. At the same time, local governments, are giving increased attention to development of local/regional agri-food systems. However, GHG mitigation efforts do not yet seem to factor into local agri-food system discussions. Although frameworks for reporting agriculture GHGs exist, local government measurement of agriculture mitigation is hampered by a lack of agriculture GHG inventories, limited data availability, and the inherent variability in agriculture emissions and removals due to the dynamic nature of farm ecosystems. With the goal of informing local governments and food system planners on the importance of agriculture GHG mitigation, this paper (1) reviews the science of GHGs, (2) describes sources of agriculture GHG emissions and illustrates potential mitigation practices, (3) discusses the variability of agriculture mitigation science, (4) highlights the importance of agriculture GHG inventories, and (5) emphasizes the necessity for local agriculture mitigation strategies.

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agriculture, carbon sequestration, climate change, food systems, greenhouse gas (GHG), GHG inventory, GHG mitigation, local governments

Introduction

The Earth's climate is changing in direct response to anthropogenic GHGs, as manifested in increasing global average air and ocean temperatures, melting of snow and ice, and rising sea levels (Intergovernmental Panel on Climate Change (IPCC), 2007a). In 2004, 77% of total global anthropogenic emissions (49,000 MtCO₂e) were from carbon dioxide (CO₂), 14% from methane (CH₄), 8% from nitrous oxide (N₂O), and 1% from other GHGs (IPCC, 2007b). The global food system is estimated to contribute at minimum one-third of all global anthropogenic emissions, more than twice that of the transport sector (IPCC, 2007a; Scialabba & Muller-Lindenlauf, 2010). Agriculture alone contributes between 10% and 25% of annual GHGs, both directly and indirectly, through land-use changes, land management, and production practices (Scialabba & Muller-Lindenlauf, 2010; Smith...Sirotenko, 2007). Methane, nitrous oxide, and carbon dioxide are considered the three¹ most important GHGs emitted from agriculture (Smith...Sirotenko, 2007; Smith, Grant, Desjardins, Worth, Li, Boles, & Huffman, 2010). In the coming decades, agriculture GHG emissions are expected to rise as the global population increases and as changes in diets (especially consumption of more animal protein) continue (Smith...Sirotenko, 2007).

The United Nations Framework Convention on Climate Change (UNFCCC) promotes mitigation and adaptation as two main options to address climate change. Mitigation involves reducing GHGs emitted into the atmosphere and removing atmospheric GHGs through the use of sinks

¹ Water vapor is an important GHG, but the effects of its emissions (especially from agriculture) are not well understood at this time, and therefore it is not included in this discussion. Refrigerants such as hydrofluorocarbons (HFCs) and perfluorocarbons (PFCs) are also associated with agriculture, but they are released in smaller quantities.

(carbon sequestration). Climate change adaptation for agriculture involves building resistance (the ability to resist the impact of a disturbance) and resilience (the ability to recover from disturbance) within agro-ecosystems, communities, and governance operations to prepare for climatic change and its impacts (Holt-Giménez, 2002; Pimm, 1984). Mitigation and adaptation differ in at least three ways including: (1) temporal and spatial scales at which the options are effective; (2) methods by which costs and benefits can be inventoried, estimated, and compared; and (3) stakeholders and governance drivers involved in their implementation (Klein, Schipper, & Dessai, 2005). Finding synergies between the two response options is considered ideal. However, due to their differences, each response requires separate attention and individual action in order to properly respond to climate change. Although the importance of adaptation is recognized, the focus of this paper is on mitigation within agriculture.

Regionally appropriate improved agriculture practices can reduce the amount of GHGs entering the atmosphere (Scialabba & Muller-Lindenlauf, 2010; Smith...Sirotenko, 2007), and carbon sequestration is considered a partial solution to short- and medium-term removal of atmospheric carbon (Hutchinson, Campbell, & Desjardins, 2007; Lal, 2009; Morgan et al., 2010). However, the science of mitigating GHGs through agriculture is sometimes variable, conflicting, and inconclusive. The scientific uncertainties around mitigating GHGs in agriculture may imply the need to postpone action while additional knowledge and greater clarity are sought, but given the urgency of climate change, agriculture mitigation planning must be vigorously pursued and strategies implemented. In fact, despite these uncertainties, a number of long-term policy decisions to mitigate GHGs are being implemented by various levels of government around the world.

Climate change mitigation strategies within agriculture must consider and address regional environmental, economic and social priorities. In British Columbia, Canada, mandated climate policies are challenging local governments to achieve signifi-

cant GHG reduction targets within their operations. Since 2008, local government attention has focused on where the greatest GHG reductions are perceived to exist, namely, transportation, waste, and buildings. At the same time, local and regional agri-food systems strategies are being pursued to achieve food security and public health goals. However, the merging of GHG emissions reductions and regional food system planning has been limited. With the goal of raising awareness of the necessity for agriculture GHG mitigation planning by local governments, the objective of this paper is to give an overview of the pertinent scientific information. Specifically, we (1) review the science around climate change and GHG emissions, (2) identify sources of agriculture emissions and illustrate potential mitigation practices, (3) discuss the uncertainties associated with agriculture mitigation, (4) describe agriculture GHG inventories, and (5) highlight the need for local governments to engage in measuring and monitoring agriculture emissions.

Science of Greenhouse Gases (GHGs)

Greenhouse gases are a group of trace substances in our atmosphere that absorb and emit infrared radiation emanating from the Earth's surface. If it were not for trace GHGs in our atmosphere, the surface temperature of Earth would be -18°C (Jenkinson, 2010). However, since the start of the Industrial Revolution in the 1750s, human activities have substantially increased atmospheric concentrations of GHGs. For example, the atmospheric concentration of carbon dioxide (CO_2) has increased from 280 parts per million (ppm) in the 1750s to 379 ppm in 2005. Within the same time frame, methane (CH_4) concentrations have increased from 715 parts per billion (ppb) to 1774 ppb, and nitrous oxide (N_2O) has increased from about 270 ppb to 319 ppb (IPCC, 2007a).

A GHGs' ability to contribute to global warming, referred to as global warming potential (GWP), is determined by its atmospheric lifetime and capacity to trap heat over a given period of time. GWP compares the mass of a particular gas relative to the same mass of carbon dioxide. For example, evaluated over a 100-year time frame, one unit of N_2O has a GWP 296 times that of one unit of

CO_2 , and CH_4 has a GWP 23 times one unit of CO_2 (Forster et al., 2007). To describe the flow of GHGs into the atmosphere, researchers use carbon dioxide equivalents (CO_2e) as the unit of measure. The CO_2e value is obtained by multiplying the total quantity (mass) of a gaseous emission by its GWP. MtCO_2e is the standard measurement of the amount of CO_2 emissions that are reduced or secluded from our environment, and stands for metric tonne (ton) carbon dioxide equivalent. A ton of carbon dioxide equals 2204.62 pounds of CO_2 ("Common Questions About MtCO_2 ," 2008).

Sources of Agriculture GHG Emissions

Methane: Methane emissions from agriculture are associated with the decomposition of organic materials (plant debris and animal wastes) in anaerobic (without oxygen) conditions, from ruminant livestock digestion (enteric fermentation in cattle, sheep, and goats), stored manures, and crops grown in flooded conditions (such as rice). CH_4 emissions from animal waste can be reduced through improved storage and handling of waste (e.g., covering manure pits) and through the use of anaerobic digesters (Smith...Sirotenko, 2007). Decomposing manures also release N_2O , which complicates manure management mitigation strategies because certain practices that decrease CH_4 may increase N_2O . Composting manures rather than leaving them as liquid slurry, for example, was found to decrease CH_4 emissions but to increase N_2O emissions (Paustian et al., 2004). CH_4 emissions from enteric fermentation can be mitigated by dietary manipulation² (such as replacing forages with concentrates [e.g., starch or fiber], improving pasture quality, optimizing protein intake, etc.), breeding for lower emitting animals, and using dietary additives (such as probiotics) that suppress bacteria that produce methane (Eagle, Henry, Olander, Haugen-Kozyra, Millar, & Roberton, 2010; Smith...Sirotenko, 2007; Smith et al., 2008).

² There is ongoing discussion about GHG mitigation by dietary manipulation of cattle due to differences in methodologies and regional practices. This discussion is beyond the scope of this paper.

Nitrous Oxide: Nitrous oxide is released when bacteria mineralize nitrogenous substances in soils and manure pits, and when synthetic nitrogenous fertilizers applied to fields volatilize into the atmosphere. Soil microorganisms produce N₂O emissions through two microbial soil processes: nitrification (conversion of ammonium [NH₄⁺] to nitrate nitrogen [NO₃⁻]) and denitrification (conversion of nitrate nitrogen [NO₃⁻] to dinitrogen [N₂O]). The most important conditions that affect N₂O emissions from fields treated with fertilizers containing ammonium and nitrate include (1) environmental factors such as ambient temperature, soil oxygen concentrations, soil texture, and soil pH, and (2) farm management and crop production practices such as fertilizer type used, application rate (the amount of ammonium [NH₄⁺] and nitrate [NO₃⁻] present for nitrification and denitrification, respectively), timing and method of application, and type of crop species treated (with major differences between grasses, legumes, and annual crops) (IFA/FAO, 2001). Recommended practices to reduce N₂O emissions from production agriculture activities include changing nitrogen fertilizer sources (e.g., changing from anhydrous ammonia or urea to slow-release fertilizers or biological sources), using nitrification inhibitors, minimizing N fertilizer rates, calibrating N fertilizer application to crop needs, and adjusting N fertilizer placement (Eagle et al., 2010; Scialabba & Muller-Lindenlauf, 2010; Smith...Sirotenko, 2007; Snyder, Bruulsema, Jensen, & Fixen, 2009).

Carbon Dioxide: Carbon dioxide from agriculture activities is generated directly from microbial decomposition of organic matter, biomass burning, and on-farm combustion of fossil fuels to run machinery. CO₂ is generated indirectly from the manufacturing and transport of various production inputs (e.g., pesticides and fertilizers) and from farm infrastructure (Lal, 2004). Recognized practices to reduce production agriculture CO₂ emissions include minimizing external inputs (e.g., pesticides and fertilizers), improving energy efficiency of farm machinery and minimizing their use, improving irrigation practices (through appropriate scheduling and application mechanisms), minimizing fuel-consuming operations, switching

fuel sources (from gasoline and diesel to natural gas, ethanol, or biofuel), implementing on-farm renewable energy production (e.g., anaerobic digesters, solar, wind, geothermal or hydroelectric power), establishing biofuel plantations on degraded soils, and reducing loss of soil organic carbon by increasing soil organic matter content via incorporation (e.g., shifting to conservation tillage or no-till, retaining crop residues, avoiding burning residues) (Eagle et al., 2010; Kruger et al., 2010; Lal, 2004; Niggli, Fliebbach, Hepperly, & Scialabba, 2009; Smith...Sirotenko, 2007).

Carbon Sequestration: The sequestration, or holding, of carbon refers to the transfer of carbon dioxide (CO₂) from the atmosphere to plants, soils, and fauna in the terrestrial biosphere (Nelson, 2009). Carbon dioxide is the only GHG that can be removed from the atmosphere and sequestered on the farm. Currently, carbon sequestration is the most cost-effective short-term option for reducing CO₂ in the atmosphere. However, estimates indicate that carbon sequestration can only make modest contributions to mitigating anthropogenic CO₂ (Hutchinson et al., 2007; Lal, 2009; Morgan et al., 2010) and it is important to recognize that soil C sequestration is nonpermanent, difficult to verify, and not a substitute for, but rather a complement to, GHG emission reduction strategies (Lal & Follett, 2009). Recommended methods to increase on-farm carbon sequestration include restoring organic (histosol/peat) soils and wetlands, converting cropland to grassland, woodland, or natural ecosystems, implementing agroforestry (e.g., alley cropping, shelterbelts, silvopasture, riparian buffers, and windbreaks), using short-rotation woody crops, switching from annual to perennial crops, using organic amendments including biochar, improving management of rangelands (uncultivated) and pasture (cultivated), using winter cover crops, eliminating or minimizing summer fallow, using diversified crop rotations, and improving irrigation practices to support optimum plant growth (Eagle et al., 2010; Hutchinson et al., 2007; Morgan et al., 2010; Powlson, Whitmore, & Goulding, 2011).

Variability of Agriculture Emissions: The Uncertain Science

The science of agriculture GHG mitigation is inexact and the uncertainties associated with agricultural emissions range between 13% and 100% (Meridian Institute, 2011). On-farm agriculture emissions can come from mechanical sources and from nonmechanical sources (Russell, 2011). Generally, mechanical sources of GHGs — those associated with purchased energy to run machinery — are easier to estimate than nonmechanical sources. Nonmechanical GHG emissions result from a variety of biochemical processes that occur in soils, air, plants, and animals. The uncertainty of nonmechanical emission sources is due to the dynamic nature of agro-ecosystems, which are influenced by many factors. Specific factors that can influence nonmechanical GHG fluxes from agricultural lands include climate, topography, land use, land cover, soil characteristics, soil management, crop management, livestock management, and input management (Moreau, Adams, Mullinix, Fallick, & Condon, 2011). The science around agro-ecosystem GHG emissions is further complicated because agricultural land acts both as a source and a sink for GHGs. This balance between GHG emissions and removal on agriculture land varies over time and space, and current estimates are uncertain (Smith...Sirotenko, 2007).

Agriculture GHG Emission Inventories: One Manages What One Measures

The measurement, reporting, and verification (MRV) of GHG emissions through inventories is considered fundamental to emissions management and reductions because it quantifies emission rates and provides essential baseline data from which prioritized reduction strategies can be developed (Russell, 2011). Inventories also provide an integral part of the monitoring process by which reduction strategies can be evaluated (British Columbia Ministry of Community Sport and Cultural Development, 2010). The development, compilation, and reporting of GHG emissions are done in accordance with the UNFCCC using the IPCC quantification guidelines (Intergovernmental Panel on Climate Change, 2006). The IPCC

guidelines cover categories of emissions by sources and removal by sinks. The GHG Protocol Initiative is another key global agency working to build effective standards for GHG emission accounting and reporting (Greenhouse Gas Protocol, 2011).

National Inventories: In Canada, the National Inventory Report (NIR) is used to account for national GHG emissions to international agencies. It includes agricultural emissions from enteric fermentation, manure management, and direct and indirect emissions from soil (Environment Canada, 2010). In 2008, inventories indicated that Canadian agriculture accounted for approximately 8.5% of total national GHG emissions. Of the 8.5% from agriculture, 51% comes from soils, 35.5% from enteric fermentation, and 12% from manure management (Environment Canada, 2010). Agriculture emissions not included in the Canadian NIR were from on-farm fuel consumption (these emissions are accounted for in the Energy sector inventories), embedded emissions in machinery and infrastructure, land-use changes, agri-chemical manufacture and transport, biological fixation by legume-rhizobium association, methane emissions from Canadian rice production, and field burning of crop residues.

Provincial Inventories: In B.C., provincial GHG inventories are conducted using national and international reporting methodologies (BC Ministry of Environment, 2010a). The first, *British Columbia Greenhouse Gas Inventory Report 2007*, provides the baseline against which subsequent reports will be compared. Similar to the national emission reports, agriculture emissions inventoried include enteric fermentation, manure management, and direct and indirect emissions from soil (BC Ministry of Environment, 2010b). Provincial inventories indicate that agriculture accounts for 3.8% of total emissions: 50% from enteric fermentation, 33% from soils, and 17% from manure management. The low apparent emissions from agriculture reflect accounting methodologies that do not incorporate agriculture's full contribution to anthropogenic GHG emissions.

Local Government Inventories: In contrast to provincial, national, and international emissions reporting guidelines, there are no defined protocols for local government monitoring and reporting of GHG emissions associated with agriculture. At the regional level where we live, Metro Vancouver participates in the preparation of the *Lower Fraser Valley Emission Inventory* that accounts for agriculture GHG estimates (Metro Vancouver, 2007). However, individual municipalities currently conduct assessments of GHG emissions from buildings, transportation, and solid waste only and do not account for agriculture within their Community Energy and Emissions Inventories (CEEIs). Although some municipalities collect data on enteric fermentation, these emissions are described only as “memo items” and are not included in total area emission calculations. As a result, no agriculture emission estimates are accounted for in the total reported emissions from municipalities in British Columbia (BC Ministry of Environment, 2010a). Reasons for agricultural CH₄ exclusion from the municipal inventories include (1) emission values used in national estimates for manure management do not reflect variable regional or local environmental conditions; (2) variation in farm practices greatly affects manure emissions; and (3) B.C. lacks systematic observation and measurement of various farm practices. For N₂O, the main reason for exclusion is a lack of information at the local level.

Discussion

Food system planning is confronted with the daunting challenge of mitigating and adapting to climate change while simultaneously ensuring food security, economic prosperity, community development, human health, and the advancement of sustainable agri-food systems. The uncertain science of agriculture GHG mitigation poses a unique challenge for food system mitigation and adaptation planning. This uncertainty, and the fact that there is no globally applicable list of mitigating practices, highlights the importance for local governments and food system planners to identify regional sources of emissions and factors affecting them and then to identify opportunities for improved efficiencies and prioritize early action

items. Furthermore, long-term climate change policy decisions by governments are mandating significant GHG emissions reductions in all sectors of human enterprise. Food system planning that does not address GHG mitigation and adaptation will be vulnerable to anticipated climate changes and to the political, economic, and social repercussions of not doing so.

Ultimately, climate change mitigation within the agricultural sector must occur at the local level through the combined efforts of farmers, non-government organizations, communities, scientists, industry, planners, and local governments. Planning for agriculture mitigation requires developing strategies that strengthen agricultural GHG inventories and identifying and prioritizing regionally appropriate actions that reduce GHGs. As part of this, it is essential to conduct research related to agriculture, economics, and policy.

Generally, agriculture GHG emissions inventories tend to give a diminished impression of the sector's impact because many emission sources are either accounted for in other inventories (e.g., on-farm fuel consumption is accounted for in the energy inventory) or not at all (e.g., embedded emissions in machinery and infrastructure). Despite the challenges and uncertainties associated with obtaining agriculture emissions data, not accounting for them in municipal inventories means there is no baseline data from which prioritized and place-specific reduction strategies can be identified, let alone promoted. Furthermore, excluding agriculture from GHG inventories suggests to the local government and the agriculture communities within their jurisdiction that GHG mitigation in agriculture is not pertinent and pressing, when indeed it is.

A number of important agricultural research questions that need to be answered have been identified (Pretty et al., 2010) and some that are specific to mitigation include exploring (1) how can global food production be increased while simultaneously reducing emissions, (2) what do low input production or carbon-neutral systems look like and how can they be designed, and (3) how can

crop breeding, new technologies, improved agronomic practices, and integrated cropping systems improve mitigation efforts?

Economic drivers, barriers, and implications of climate change mitigation need to be explored further at local levels. Financial incentives, investment policies, and other market mechanisms (such as carbon trading, carbon taxes, offset markets, payment for environmental services, and preferential support for local agri-food systems) are examples of tools and strategies that may assist farmers in adopting regionally appropriate mitigation practices that may be otherwise cost-prohibitive. However, research is vitally needed to determine the potential impacts of such strategies and to understand under what circumstances such strategies achieve the greatest economic, societal, and environmental good. Early investment in mitigation and adaptation actions is essential to building long-term resilience of the sector (Meridian Institute, 2011).

Policy plays an essential role in enabling climate change mitigation within the agricultural sector. However, understanding and navigating policy and regulatory constructs are supremely complicated due to the interacting influences and directives of policies (some climate-focused and others not) that directly affect agriculture (see Moreau, Moore, & Mullinex, 2012, in this issue). Analyzing policy at the local level is critical to agricultural climate change planning in order to identify key influencing policies that will directly or indirectly affect mitigation strategies (Smith...Towprayoon, 2007). Furthermore, policy synergies, conflicts, and contradictions need to be understood.

Conclusions

The agricultural sector is vital to sustainable human existence, and therefore we cannot ignore the real and substantial role that agriculture plays in GHG emissions nor the potentially catastrophic effects on food security and sustainability if planning for the sector does not consider climate changes. In summarizing the scientific information relating to agriculture GHG mitigation, we hope to have presented and framed the pertinent information

necessary for local food system planners to begin to make planning decisions that are informed and appropriate relative to climate change and agri-food systems. We also hope that this review and subsequent discussions will prompt local agri-food system planners to advocate for the information and resources they need to accomplish the critically important task of promoting the mitigation of production agriculture's GHG emissions at the local level. Finally, because the science around production agriculture and climate change denies conclusive direction, we cannot delay: time is of the essence. Community and regional planners must begin to address sustainable agri-food systems and greenhouse gas mitigation. 

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