Opportunities for Agriculture to Mitigate Greenhouse Gases: A Grass Roots Approach

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Keith Paustian

Senior Research Scientist
Natural Resource Ecology Laboratory
Colorado State University
Fort Collins, CO 80535

An overview of agriculture and greenhouse gases

In recent years, the concerns about changes to our earth's atmosphere through human activities and the potential consequences for our climate and environment have become familiar to most of us. However, the role of agriculture as a partial cause of and a potential solution to the problem is not so well known. We know that concentrations of three of the major greenhouse gases, carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) have risen dramatically over the past 200 years, mostly through human activities (Slide 2).[1] Carbon dioxide in the atmosphere has increased by about 30% since 1800 and is now higher than anytime in the past several hundred thousand years and continues to increase by about 0.5% per year. Methane concentrations have doubled over the past 200 years while nitrous oxide, one of the most potent greenhouse gases, has increased by 10% over the same period. Most of the recent increase in CO_2 is due to the burning of fossil fuels. However, for methane and nitrous oxide, agriculture is one of the major sources of the emissions. Also, in some parts of the world, deforestation and conversion of lands to agricultural uses is a major source of CO_2. Looking at the combined effects of greenhouse gases, expressed as "Global Warming Potential" (GWP), agriculture world-wide accounts for about 20% of the current increase in GWP. For CO_2, agriculturally related emission sources include deforestation and landuse change (primarily in the tropics), use of fossil fuels by farm machinery and agrochemical production, and soil degradation. Methane is produced from ruminant livestock, animal manure and rice cultivation. Major sources of nitrous oxide include nitrogen fertilizers and leguminous crop plants.

However, these same problems represent unique opportunities for agriculture to not only reduce it's own greenhouse gas emissions but to help offset carbon dioxide emissions from other sectors of the economy (Slide 3). Perhaps most importantly, the practices needed to achieve these goals can yield substantial benefits in terms of cleaner air and water, healthier soils and economic opportunities for farmers and ranchers. There are a wide variety of agricultural practices that can mitigate carbon-dioxide, methane and nitrous oxide emissions. The use of crops and crop residues for biofuels can substitute for fossil fuel use, hence reducing fossil fuel-derived CO_2, and provide a new income source for producers. Carbon sequestration, which I will focus on in the main part of my presentation, can remove CO_2 from the atmosphere while building the humus content and fertility of our soils. Methane capture from manure facilities and its use for fuel not only reduces methane emissions but represents a renewable energy source. Especially

[1] IPCC. 1996. Climate Change 1995: The Science of Climate Change. J.T. Houghton, L.B. Meira Filho, B.A. Callander, N. Harris, A. Kattenberg, and K. Maskell (Eds.). Intergovernmental Panel on Climate Change. Cambridge University Press. Cambridge. 572 pp.

in Europe and Asia, large livestock operations are installing commercially viable methane capture and electrical generating facilities. Improvements in technology will likely extend this reach to smaller livestock operations in the future. Improving the quality and digestibility of forage can reduce methane production from ruminant digestion. More efficient use of fertilizers and improved fertilizer technology can cut emissions of nitrous oxide as well as improve water quality and cut fertilizer costs for farmers.

Agriculture and soil carbon sequestration

For the remainder of my talk I will focus on how agriculture can reduce the buildup of CO_2 in the atmosphere by sequestering carbon as organic matter in soils, and at the same time provide substantial improvements in soil, water and air quality. Carbon is the main constituent of all living things and the cycling of carbon between the atmosphere and the biosphere is the basis for life on earth (Slide 4). Plants capture CO_2 through the process of photosynthesis, which is the source for all plant growth. Plant materials from roots and non-harvested residues are returned to the soil where they are decomposed over time by soil microorganisms (e.g. bacteria, fungi) and soil fauna (e.g. earthworms, insects), with carbon returned to the atmosphere as CO_2. However portions of this decomposing organic matter can reside in soil for decades or centuries, in stable forms that confer much of the natural fertility of soils. The amount of carbon that resides in the soil is governed by the balance between the rate of carbon addition (mainly through plant sources) and the rate of carbon loss, mainly as CO_2 from decomposition. These processes of carbon input and output are governed by external factors such as climate and soil physical properties, but also by management. The basic idea behind carbon sequestration is to use *management* to increase the rate of carbon added to soil and/or reduce the rate of organic matter decomposition in soil, thereby increasing the storage of carbon in the soil and removing it from the atmosphere [2].

Historically, past agricultural practices tended to shift the carbon balance towards low rates of carbon inputs and high carbon losses, thus depleting the amount of carbon in the soil compared to the original prairie and forest soils (Slide 5). Low productivity and widespread residue removal (e.g. burning) resulted in reduced rates of carbon additions. Frequent and intensive tillage, often accompanied by increased soil erosion, tended to accelerate decomposition and CO_2 emissions. However, trends in agricultural production practices, particularly over the past 10-20 years, have begun to reverse this process, favoring a rebuilding of the carbon stocks of agricultural soils (Slide 6). Improvements in crop productivity, and increasing the time period over which plants are occupying the soil, through winter cover crops or by reducing the frequency of summer fallowing are examples of activities that promote higher carbon inputs to soils. Use of reduced till and no-till cropping practices tend to slow the decomposition of soil organic matter. Planting and maintaining perennial grasses on Conservation Reserve Program lands as well as in conservation buffers (e.g. grass waterways, field buffers, filter strips, terrace walls) both increase carbon inputs, since more carbon tends to be allocated to the roots of perennial grasses, and eliminate tillage disturbance and reduce soil erosion.

Recent estimates are that US agricultural soils are currently a net *sink* for carbon and that the amount of carbon stored in agricultural soils is increasing at a rate of around 20 million metric

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[2] Paustian, K., C.V. Cole, D. Sauerbeck and N. Sampson. 1998. CO_2 mitigation by agriculture: An overview. Climatic Change 40:135-162.

tonnes per year (Slide 7).[3] This is somewhat less than the amount of carbon emitted as CO_2 from the use of fossil fuels to operate farm machinery and to produce and distribute fertilizers and pesticides. However, its estimated that with widespread adoption of the existing conservation practices mentioned above, US agriculture soils have the potential to sequester carbon at rates of 75-200 million metric tons per year over the next two to three decades.[4, 5] Rates might be further enhanced by developing crop varieties that capture more carbon from the atmosphere, allocate more of their carbon to roots and/or produce slower decomposing residues and through other new technologies. However, there are also social, economic and technical barriers to achieving these high levels of carbon sequestration that need to be considered in formulating policies designed to promote agricultural mitigation of greenhouse gas increases. Likewise it is important to consider the effects of policies and management practices on all the greenhouse gases, to ensure that the greatest overall environmental, social and economic benefits are achieved.

State and county-level assessment of soil carbon sequestration: A case study in Iowa.
In order to design and assess mitigation strategies, we need to quantify, and make projections of how various management and land use practices affect carbon sequestration - taking into consideration the influences of climate and soil characteristics, which vary geographically. I'll briefly describe an approach that we have been using to assess current and potential rates of carbon sequestration in agricultural soils in the state of Iowa (and similar projects are ongoing in several other states) (Slide 8). The project was done in partnership with the USDA/Natural Resource Service (NRCS) as well as several state-agencies (e.g. Dept. of Agriculture, Dept. of Natural Resources, Iowa State University), the Iowa Association of Conservation Districts and the National Association of Conservation Districts, with input from USDA/Agricultural Research Service. A key element in the assessment was the 'grass-roots' involvement of local participants in each of the state's Conservation Districts (county-based), who participated in educational and training sessions on greenhouse gases and carbon sequestration and collected county-specific data for use in the analysis. The assessment method (Slide 9) employed a computer model, called the Century model, capable of simulating soil carbon changes as a function of management, climate and soil variables (Slide 10). The model has been validated using a number of long-term field experiments across the Corn Belt, where soil carbon responses to management have been measured, under a variety of soil and climate conditions. Several geographic databases - on climate, soil properties and general land use, most of which have been developed by NRCS and are available nation-wide - provided some of the input data necessary for the analysis. Finally, local conservation districts provided detailed data, specific to each county, on a variety of current and historical management practices that affect soil carbon dynamics, which had not previously been compiled (Slide 11). Following an initial training session, each county was provided with maps of historical and current land cover and land use, overlain with soil associations (Slide 12), to provide a geographic perspective of soil and

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[3] Eve, M., K. Paustian, R. Follett and E.T. Elliott. 2001. An inventory of carbon emissions and sequestration in US cropland soils. In: R. Lal and K. McSweeney (eds) Soil Management for Enhancing Carbon Sequestration. Soil Science Society of America, Special Publication, Madison, WI. (in press).

[4] Bruce, J.P., M. Frome, E. Haites, H. Janzen, R. Lal and K. Paustian. 1999. Carbon sequestration in soils. Journal of Soil and Water Conservation 54:382-389.

[5] Lal, R., R.F. Follett, J. Kimble, and C.V. Cole. 1999. Managing U.S. cropland to sequester carbon in soil. Journal of Soil Water Conservation 54:374-381.

vegetation conditions within their counties. Data on historical and current management, including land use, drainage, cropping history, fertilizer management and conservation practices were compiled in spreadsheets, comprising the 'Carbon Sequestration Rural Appraisal' (Slide 13). Based on all of these data, we developed data input files that contained a suite of management histories and current practices which were then modeled for all the major soil types within each county in the state. This procedure resulted in more than 200,000 individual simulations, reflecting the large number of combinations of climate, soil and management conditions existing across the state (Slide 14). The results from the assessment were compiled into a database that can be queried by local managers by county and soil type, to display estimated changes in soil carbon for a variety of different management alternatives (Slide 15). The data were also compiled to produce a number of state-level maps and summary tables. Estimates of carbon sequestration rates for Iowa, aggregated for major categories of land use, are shown in the table (Slide 16). The assessment suggests that Iowa soils are presently accumulating soil carbon at the rate of about 3 million metric tonnes per year, mainly through the increased adoption of conservation tillage and the conversion of annual cropland to Conservation Reserve Program land and conservation buffers over the past 10-20 years. This rate of carbon sequestration is equivalent to an offset of about 15% of total fossil fuel CO_2 emissions in the state of Iowa. We estimated that a more widespread adoption of conservation tillage, especially no-till, along with other conservation practices could more than double the present rate of carbon sequestration. Thus in Iowa, carbon sequestration in agricultural soils represents a significant mitigation option.

New research and development initiatives for agricultural mitigation of greenhouse gases

To help realize the opportunities for agriculture to contribute to the mitigation of the increasing greenhouse gas emissions to the atmosphere, a broad-based research and development program is needed. To help meet this need, a group of nine land-grant universities (including Colorado State, Iowa State, Kansas State, Michigan State, Montana State, Ohio State, Purdue, Texas A&M and Nebraska, together with Battelle-Pacific Northwest National Laboratory) formed the 'Consortium for Agricultural Soils Mitigation of Greenhouse Gases' (Slide 17) or CASMGS (pronounced like 'chasms'). Investigators at these institutions are among the leaders in the US and world-wide in the fields of soil carbon dynamics, soil-derived greenhouse gases, computer modeling, natural resource data analysis, agricultural resource economics and integrated assessment. The mission of the Consortium is to provide to land managers, policy makers and other stakeholders, the tools and information needed to successfully implement and assess soil carbon sequestration and greenhouse gas reduction programs dealing with agriculture. Research priorities include 1) basic research on understanding and manipulating the processes and mechanisms controlling carbon sequestration and greenhouse gas (GHG) emissions, 2) evaluating and designing 'best management practices' for carbon sequestration and greenhouse gas mitigation, 3) predicting and assessing carbon sequestration and GHG emissions and mitigation, including environmental, management and economic components, at local, regional and national scales, 4) developing and assessing measurement and monitoring technologies for carbon sequestration and GHG emissions and 5) providing outreach, education and decision-support tools to a wide variety of stakeholders. Work in these areas is ongoing with Congressional mandated funding from USDA and EPA, along with related research funded from other sources, including DOE. In addition, CASMGS research is being carried out in close collaboration with investigators from USDA agencies, including the Agricultural Research Service, Natural Resource Conservation Service and Economic Research Service.

In conclusion, there is strong evidence that agriculture can play a significant role in efforts, both in the US and elsewhere in the world, to mitigate the increase of greenhouse gases in the atmosphere. There are a variety of mitigation opportunities, which can not only help address agriculture's own contribution to the problem but also help offset emissions from other sectors of the economy. Activities such as biofuel and biogas production and carbon sequestration represent potential new sources of income for farmers and ranchers. In addition to reducing CO_2, many practices that enhance carbon sequestration have important environmental benefits for improving soil and water quality, reducing soil erosion and enhancing the productivity and sustainability of our agricultural production systems. The scientific basis for quantifying and assessing soil carbon sequestration is progressing rapidly, with new information coming available to assist policy- and decision-making. To fully capitalize on these opportunities – further research, education and outreach are needed, and recent national initiatives are helping to meet those needs.