



Research note

GRACEnet: Greenhouse gas reduction through agricultural carbon enhancement network

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Abstract

GRACEnet (greenhouse gas reduction through agricultural carbon enhancement network) is a new research program initiated by the Agricultural Research Service (ARS) of the United States Department of Agriculture (USDA). The primary objectives of GRACEnet are to identify and develop agricultural strategies that will enhance soil C sequestration and reduce greenhouse gas emissions and to provide a scientific basis for possible C credit and trading programs that could be used to reduce net emissions of greenhouse gases and improve environmental quality. This program will generate information on C storage in agricultural systems, which is needed by producers, program managers, and policy makers. Scenarios evaluated in GRACEnet will not only address mitigation of CO₂ emission through soil C sequestration, but also their effects on nitrous oxide (N₂O) and methane (CH₄). Both grazing lands (range and pasture) and croplands (irrigated and dryland) will be investigated. The information generated will be applicable at the local (e.g., farm or ranch), regional and national scales. GRACEnet's geographical extent, use of common procedures, and cooperation with other North American C cycle research programs will result in robust information to promote scientifically based conservation technologies that are relevant to national and international policy makers, as well as to agricultural producers and practitioners.

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1. Interest in soil carbon

Soil C sequestration has become of greater interest to farmers, ranchers, various land managers, and policy makers with recent environmental and economic analyses showing its potential role in mitigating global

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change. Policy makers have become interested, primarily because soil C sequestration is a relatively easy way of offsetting greenhouse gas emissions in the short term. Land managers have become interested, primarily because policy makers are considering C trading programs under which they could receive payments from government agencies, major carbon dioxide (CO₂) emitters such as utilities and industry, or third-party brokers for adopting practices or technologies to remove CO₂ from the air and store it in soil. In addition, soil C sequestration is attractive to all these parties, because storing C as organic matter in soil can also provide an array of benefits to the environment and agricultural production. Although the benefits of soil organic matter and many of the conditions and practices that promote its formation have been known for decades, further research would enhance our knowledge of the rate at which C could be transferred to soil, the duration of C stored in soil, and the ways soil C benefits agricultural systems and the surrounding environment.

Soil C can be sequestered in either organic or inorganic forms, although most soil C stored in association with agriculture would likely be organic. Increasing soil organic C would improve agricultural productivity and environmental quality. Productivity benefits from greater soil organic C would occur when soil organisms and organic compounds increase the retention of nutrients via biological, physical and chemical mechanisms, with concomitant decrease in the rate at which nutrients would be leached through the soil profile. Furthermore, improvements in the structure of soils, which organic C increases, would lead to improvements in water infiltration and water holding capacity and reduce soil erosion. The same soil improvements that reduce nutrient leaching and soil erosion would also contribute to retention of agricultural chemicals at intended application sites. These positive aspects of increasing soil organic C would result in a 'win-win' or 'no-regrets' situation, because despite the uncertain impact of increasing atmospheric greenhouse gases on global climate, increasing soil organic C would result in production and environmental benefits.

2. Carbon trading

Interest in soil C sequestration from national policy makers is illustrated by information provided by the

Library of Congress (<http://www.thomas.loc.gov>), which tracks legislative information on the Internet. A search conducted in late April 2004 for the phrase 'carbon sequestration' yielded 33 bills from the 108th Congress of the USA. Titles of these bills pertained to air quality, climate, forestry, wildlife, basic biology research, energy, foreign relations, and appropriations. In February 2002, the USDA was asked by the President of USA to develop: (1) targeted incentives for land managers that would promote C sequestration and (2) accounting rules and guidelines for tracking C sequestered. The USDA is developing programs and procedures that will guide voluntary C trading, sequestration, and greenhouse gas reduction activities in agriculture and forestry. These voluntary rules and guidelines are part of a larger system developed by the United States Department of Energy aimed at reducing greenhouse gases and fostering C trading. Soil C sequestration was included in the recently ratified Kyoto Protocol and can be utilized by signature nations. Voluntary C trading projects between industry and land managers are, in fact, already operational. Most of these trading projects are focused on reforestation, but soil C is the focus of at least a couple of projects in Iowa and Washington. Carbon can be traded on the Chicago Board of Trade (<http://www.cbot.com>). Interest in C sequestration and trading C credits is expanding.

3. Global warming potential

Considerations of C sequestration in agricultural lands are not related only to carbon dioxide (CO₂). Agricultural activities also emit N₂O and CH₄. Estimates of anthropogenic greenhouse gas emissions from the USA in 2002 (<http://yosemite.epa.gov/oar/globalwarming.nsf>; USEPA, 2004) suggest that agriculture contributes 1.0 Tg of N₂O or 73% of total N₂O emission, accounting for ca. 4% of the total greenhouse gas emission in the USA (expressed as CO₂ equivalents). Of the N₂O emission from agriculture, 94% arises from soil. Small amounts are emitted from animal production and waste handling (including land application of animal wastes). Nitrous oxide is emitted during both nitrification and denitrification, but the vast majority occurs during denitrification.

Agriculture is responsible for ca. 7.7 Tg of CH₄ or 27% of total CH₄ emission, accounting for ca. 2% of the total greenhouse gas emissions in the USA (expressed as CO₂ equivalents; USDA, 2004). Agriculturally derived CH₄ in the USA is produced primarily from animal production and manure handling and storage. Due to their abilities to trap gas and their long residence time in the atmosphere, CH₄ and N₂O contribute much more than CO₂ on a molecule basis to global warming. Preventing the emission of one molecule of CH₄ or N₂O has the same effect on the atmosphere as sequestering about 20 and 300 molecules of CO₂, respectively. Management of these gases in agricultural settings has implications for C storage practices and policies. Therefore, practices that decrease N₂O and CH₄ emissions are of great interest in the GRACEnet project.

The actual amount of C currently being sequestered in the USA is estimated at 8–14 Tg yr⁻¹ (Eve et al., 2002; Sperow et al., 2003). This amount is minor compared with the *potential* of soils in the USA to sequester C, which is projected as much as 220 Tg yr⁻¹ (Follett, 2001; Follett et al., 2001; Kimble et al., 2002; Lal et al., 1998, 2003). This difference represents a significant opportunity. Undoubtedly, potential for increased C sequestration exists worldwide. The current status and potential for C sequestration for different regions of North America are detailed in other articles in this issue.

We recognize that economic issues must also be considered. Some important considerations are the expected rate of C sequestration, the price offered for sequestered soil C, the ease with which producers can alter land use and management, the effects of targeting practices or regions, and the policy structure and delivery (Sperow et al., 2002).

4. GRACEnet approach

Techniques used to derive estimates of actual or potential C sequestration at regional and national scales often do not provide the level of detail useful for site-specific estimates on individual fields or farms. Carbon trading and associated policies would benefit more from increasingly robust, accurate databases than from estimation procedures (Lal et al., 2003). GRACEnet is a research forum intended to provide this empirical basis for program and policy development and implementa-

tion by land managers. In addition, it would provide valuable information to validate soil C models such as Century, DAYCENT and CQESTR (Parton et al., 1996, 1998, 2001; Paustian et al., 1996; Rickman et al., 2002).

GRACEnet was designed to provide site-specific information, as well as broad-based guidance on soil C sequestration, using a network of locations representative of the diversity of climate and crop and grazing land practices in the USA. Data will be collected from four scenarios designed to assess soil C sequestration, net global warming potential, and environmental consequences of agricultural management. These scenarios are:

1. An agricultural system that represents business as usual, i.e., the most typical agricultural management practice(s) for a crop or livestock production system in each location of the network.
2. An agricultural system that most likely maximizes soil C sequestration.
3. An agricultural system that minimizes net global warming potential. This system would differ from scenario 2, because N₂O and CH₄ emissions would be minimized in addition to sequestering soil C.
4. An agricultural system that maximizes total environmental benefits, e.g. soil, water, and air quality. This system would reflect the possibility that C sequestration could become part of a conservation benefit package. Land managers and policy makers would be interested in tradeoffs among management options and programs. For example, a farmer may wish to manage resources to balance an interest in C sequestration with a goal of minimizing nutrient load to receiving water bodies.

At many locations, management systems for determining soil C sequestration have already been established, because of research interests in improving crop production and environmental quality. GRACEnet will build upon these established studies.

GRACEnet is designed to use uniform protocols at all locations for soil sampling, trace gas measurement, micrometeorological monitoring, and plant and residue characterization. It is possible that some response variables may not be measured at some locations. Information will be collated in a common database. Details on protocols will be available on a GRACEnet website.

Each location of GRACENet will not necessarily be able to implement the four scenarios described above, especially in the early phases of the research. In particular, scenarios 3 and 4 could become functional at some locations only as capabilities develop with time. All locations will collect data on soil C sequestration under current management (scenario 1) and in a system that maximizes soil C sequestration (scenario 2). Currently ca. 15 locations are collecting trace gas (N_2O and/or CH_4) data, and we expect this number of locations to increase in the future. GRACENet is intended to be 'layered' onto existing research of agricultural systems and soils at some locations, such that obtaining information on other environmental benefits under scenario 4 would depend upon the overall objectives and scientific capability and capacity of each research unit.

Management systems to maximize soil C sequestration (scenario 2) might be either those that are currently economically feasible or those that are only limited by physical circumstances, e.g., climate and soils within a region. How economics would dictate the influence of soil C sequestration on land management decisions remains unknown. In theory, very high C payments could push C sequestration into position as a primary goal for some agricultural lands, rendering production of agricultural commodities secondary. The Conservation Reserve Program, for example, is a program whereby land is set aside from agricultural production in favor of environmental benefits. It would be reasonable to envision a program that contained soil C sequestration as the primary consideration. For the immediate future, however, it seems likely that the primary economic driver of agricultural lands will continue to be crop or animal production. Tradeoffs among soil C sequestration, net global warming potential, other environmental benefits, and yield would certainly influence decisions of land managers to change production practices for C payments. Thus, commodity yield will be a key measurement in GRACENet.

Most locations currently measuring trace gases will concentrate on N_2O , because N_2O emission is more prevalent than CH_4 emission from most agricultural soils (Mosier et al., 1991, 1996, 1997; Bronson and Mosier, 1993; Kessavalou et al., 1998; Chan and Parkin, 2001). Measurement of CH_4 emission will be most important at animal production sites and locations

where manure, biosolids and other organic matter are applied to the land. However, soils also contain methylophilic bacteria that consume CH_4 and reduce atmospheric CH_4 levels. Soil management practices will influence whether a given soil is a net source or a net sink of atmospheric CH_4 . With 15+ sites, GRACENet will have the most comprehensive database of trace gas emissions from agriculture in the USA yet developed.

5. GRACENet's relationship to other research and programs

Studies of mechanisms that drive soil C sequestration and greenhouse gas emissions will occur at many GRACENet locations depending upon the interests of the researchers. Examples include studies of clay particle and organic matter interactions and associations, relationships between soil C and other biogeochemical elements (e.g., N, P, S), manure management, and the effects of various management practices on N_2O and CO_2 dynamics. These process and mechanistic studies will enhance the interpretation of GRACENet results.

Other large-scale studies of soil C cycling are in progress, but GRACENet fills a niche that complements and is complemented by these other efforts. GRACENet is unique from the Soil Carbon Pools and Dynamics in Agroecosystems program (Paul et al., 1997; Paustian et al., 1998), because GRACENet assess more than soil C status of current practices. GRACENet will provide information on strategies to (i) increase soil C sequestration and (ii) mitigate trace gas emissions from agricultural operations. The Consortium for Agricultural Soil Mitigation of Greenhouse Gases (CASMGs; <http://www.casmgs.colostate.edu/>) and the Carbon Sequestration in Terrestrial Ecosystems (CSiTE; <http://www.csite.esd.ornl.gov/>) programs have some objectives similar to those of GRACENet, and cooperation is already occurring among groups. For example, some of the major field sites used by CSiTE in eastern Ohio and eastern Washington were developed and are being maintained by ARS. Similarly, ARS scientists are collaborating on projects supported by CASMGs. GRACENet complements these programs by expanding the geographical extent of agricultural lands being studied. GRACENet will have programmatic strength by adopting uniform protocols to

develop information useful for land managers, regulators, brokers, and policy makers. Most of the major cropping and grazing systems in the USA will be addressed with GRACEnet.

In a larger context, GRACEnet also fits within priorities and programs of the USDA Global Change Program Office (<http://www.usda.gov/agency/oce/gcpo/>). It is also being coordinated with the Climate Change Science Program (<http://www.climate-science.gov>). In particular it addresses C cycle issues such as the extent that agricultural management can be used to effectively offset emissions of C from fossil fuel combustion, regionally, nationally, and globally (<http://www.carboncyclescience.gov>). GRACEnet will develop coordination with these national programs and others internationally.

6. Summary

GRACEnet will provide agricultural producers, program managers, and policy makers information to manage soil C sequestration, engage in C trading, and reduce emission of trace gases from agricultural activities. Four agricultural management scenarios are proposed: (1) current management, (2) management to maximize soil C sequestration, (3) management to minimize net global warming potential, and (4) management to maximize total environmental benefit. Data will be collected using uniform protocols at >25 locations across the USA representing a variety of crop and animal production systems. Research cooperation with programs having similar goals both within the USA and internationally will likely occur. The geographical extent of GRACEnet, use of common procedures, and cooperation with other North American C cycle research programs will result in robust information to transfer scientifically based conservation technologies relevant to national and international policy makers, as well as to agricultural producers and practitioners on local and regional levels.

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