Simulating historical and current soil C dynamics in US agricultural systems

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ABSTRACT

National-scale information on soil C changes is needed for greenhouse gas inventories and for assessing greenhouse gas mitigation practices and policies. We describe a methodology for estimating historical and current changes in soil C stocks in agricultural soils in the US. The method is comprised of database servers, incorporating spatial and tabular data from a variety of sources, and executive programs for computation, using the Century model, within a parallel computing environment. We estimate that mineral soils in US cropland are a net sink of 20-25 Tg C per year. Changes in land use and management, including CRP land, adoption of conservation tillage (reduced till and no-till) and long-term trends of increasing productivity and C inputs on cropland are the primary drivers. In contrast, cultivated organic soils, estimated using a separate empirical method, are a net C source of about 9 Tg C per year. Ongoing refinements to the methodology include use of county-level observed weather and comprehensive uncertainty analysis.

INTRODUCTION

As a signatory member of the UN Framework Convention on Climate Change (UNFCCC), the US is obligated to report an annual inventory of greenhouse gas (GHG) emissions and removals for all sectors of the economy. Agriculture is both a source and sink of the three major GHGs, CO_2, N_2O and CH_4 and soils are a major source/sink category. Inventory estimates for soil CO_2 emissions/removals have been estimated over the past several years (Eve et al. 2001, 2002, Ogle et al. 2003) , using empirically-derive methods, based on the IPCC guidelines, with successive refinements including derivation of US-specific model coefficients and statistically-based uncertainty estimates (Ogle et al. 2003). A further refinement in the inventory method is being developed, applying a dynamic simulation-based approach, shown here. Advantages to this approach include: 1) ability to incorporate a wider spectrum of land use and management activities, 2) inclusion of productivity trends that are general across different management regimes, 3) finer-grain representation of climate and soil effects on soil C dynamics and 4) inclusion of interannual climate variability effects on soil C.

DATA SOURCES

Input data were obtained from several sources. Data from more than 80 long-term experiments in North America were used for verification of the simulation model at the national level. For inventory calculations, the primary data set was the National Resources Inventory (NRI). The model was simulated for each NRI point having a unique cropping sequence and soil type, within each Major Land Resource Area (MLRA). Climate variables were defined for each MLRA from the PRISM climate database. All major field crops (maize, wheat and other small grains, soybean, sorghum, cotton) as well as hay and pasture (grass, alfalfa, clover) were simulated. Management variables included tillage, fertilization, irrigation, drainage, and manure addition. Auxiliary data on management practices was obtained from the Conservation Technology Information Center (CTIC), USDA-ERS Cropping Practices Survey, USDA AgCensus and NASS. MLRAs having less than 5 percent of total area in crop production were excluded. The cropland area represented in the inventory was 149 Mha.

METHODS

The inventory framework combines spatial and tabular data into a two-stage MySQL/Access ® database server. Data input to the Century model (Metherell et al. 1993, Parton et al. 1994) is configured for use in a parallel processing cluster, controlled by executive programs written in Perl. Output from the model is then compiled in the database tool for post-processing.

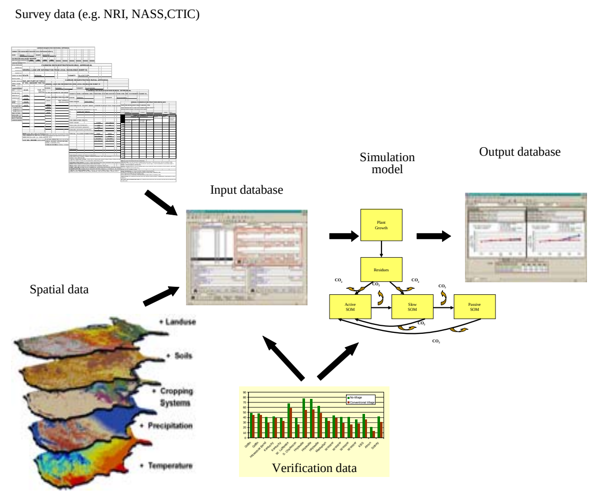

Fig. 1. Inventory analytical framework.

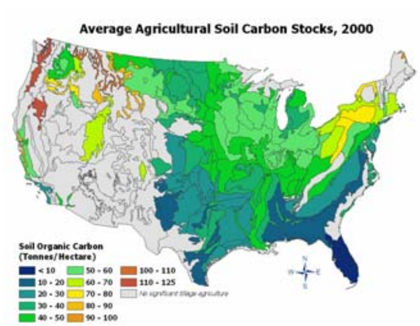

Fig. 2. Modeled SOC stocks (0-20 cm) based on climate, soil and historical land use.

RESULTS AND DISCUSSION

Simulated cropland SOC stocks, averaged by MLRA, largely reflect broad climatic gradients, with highest levels in the upper Midwest-Great Lakes region and in coastal PNW (Fig. 2). Changes in cropland C stocks (Fig. 3) are more geographically variable, depending on *interactions* of climate and soils with changes in land use and management. Highest rates of SOC accumulation, averaged for total cropland within each MLRA, are predicted in the NE and Ohio Valley, Northern Great Plains and PNW. Lower rates are occurring in areas of the South and in intensively managed regions of the Midwest (e.g. Des Moines Lobe).

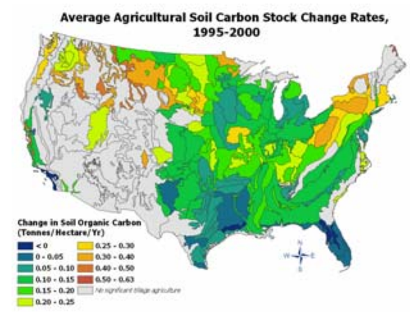

Fig. 3. Simulated SOC stock changes, averaged for total cropland area in each MRLA

The model suggests that soil C has been increasing by around 15-25 Tg/yr over the past two decades (Fig. 4). Changes in management responsible for the current increase in SOC stocks are largely through increased adoption of conservation tillage and the CRP (Fig. 5), although 35% of the current increase is occurring for other reasons (e.g. reduced summer fallow, hay/pasture management), including long-term increases in productivity and C inputs, overall on US cropland. Sequestration rates estimated with this method (Fig. 6) are roughly double those derived using the IPCC methodology (Ogle et al. 2003), which does not account for overall trends in productivity and C inputs.

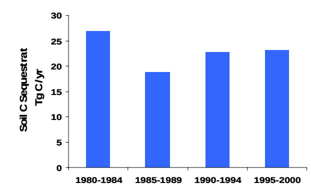

Fig. 4. Estimated annual rates of C sequestration since 1980.

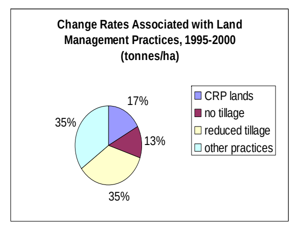

Fig. 5. Main sources of soil C stock change.

Δ SOC (Tg C/yr) in U.S. Agricultural Lands (1995-2000)

	IPCC method	Century method
Mineral Soils	11.1 (6.5 to 16.1)*	23.1
Organic Soils	-9.5 (-6.4 to –13.4)	-9.5 (from IPCC)
Total	1.6 (-4.3 to 7.6)	13.6

*95% Confidence interval.

Fig. 6. Comparison of Century- and IPCC-based inventory results.

REFERENCES

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. Pp. 51- 65. SSSA Special Publ., Madison, WI.

Eve, M.D., M. Sperow, K. Paustian and R.F. Follett. 2002. National-scale estimation of changes in soil carbon stocks on agricultural lands. Environmental Pollution 116: 431-438.

Metherell, A. K., L.A. Harding, C.V. Cole, and W.J. Parton. 1993. CENTURY Soil organic matter model environment. Agroecosystem version 4.0. Technical documentation. GPSR Tech. Report No. 4, USDA/ARS, Ft. Collins, CO.

Ogle, S.M., F.J. Breidt, M.D. Eve and K. Paustian. 2003. Uncertainty in Estimating Land Use and Management Impacts on Soil Organic Carbon Storage for U.S. Agricultural Lands between 1982 and 1997. Global Change Biology 9:1521-1542.

Parton, W.J., D.S. Ojima, C.V. Cole and D.S. Schimel. 1994. A general model for soil organic matter dynamics: Sensitivity to litter chemistry, texture and management. In: Quantitative Modeling of Soil Forming Processes. Special Publication 39, Soil Science Society of America, Madison, WI, pp. 147-167.