Methods for Measuring and Monitoring Soil Carbon Sequestration

R. César Izaurralde
PNNL, Joint Global Change Research Institute
www.globalchange.umd.edu

Charles W. Rice
Kansas State University

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Pacific Northwest National Laboratory

Measuring and monitoring soil C sequestration: a new challenge?

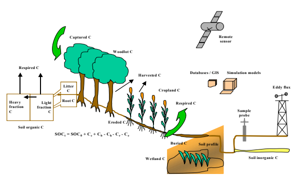
Long term experiments have been essential tools to understand the temporal dynamics of soil C

Soil survey maps can be used to estimate the spatial distribution of soil organic C stocks

The challenge consists in developing cost-effective methods for detecting changes in soil organic C that occur in fields as a result of changes in management

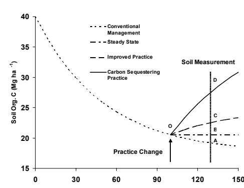
On the question of detecting, measuring and scaling soil carbon sequestration

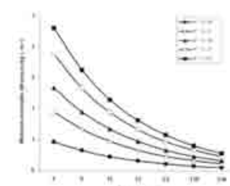
- Detecting changes in soil C stocks
  - Difficult in the short term
  - Changes to be detected small compared to total C stocks
- Methods for detecting and scaling soil C sequestration
  - Direct methods
    - Field and laboratory measurements
      - Soil sampling
      - Wet and dry combustion
    - Eddy covariance
  - Indirect methods
    - Accounting
      - Stratified accounting with databases
      - Remote sensing
    - Simulation modeling
      - Century, DayCent
      - RothC
      - EPIC, APEX
      - DNDC
      - DSSAT



Post et al. (2001)

When do we sample? How many soil samples?

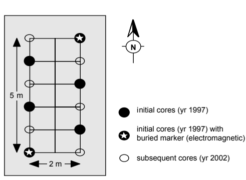




Izaurralde and Rice (2006)

Soil sampling protocol used in the Prairie Soil Carbon Balance (PSCB) project in Canada

- Use "microsites" (4 x 7 m) to reduce spatial variability
- Three to six microsites per site
- Calculate soil C storage on a soil mass equivalence basis
- Analyze samples at the same time
- Detection of soil C changes in 3 years
  - 0.71 Mg C ha^{-1} – semiarid
  - 1.25 Mg C ha^{-1} – subhumid

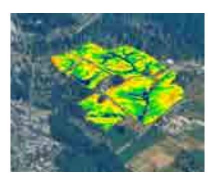


Ellert et al. (2001)

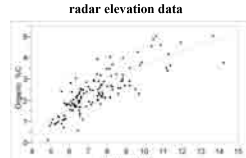
McConkey et al. (2001)

Quantitative mapping of soil organic C

- Hypothesis: Field scale variability often predictable from topographic data
- Available GIS data (remote sensing, terrain models, soil maps, precision farming) can be used to map large areas with a minimum number of samples
- Carbon strongly predicted from terrain (wetness index) in Iowa (glacially-derived Mollisolls)
- Relationships between C and topography are much weaker in older soils (Ultisolls) from Ohio and Maryland



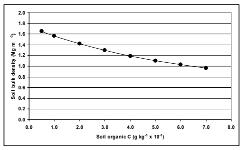
Map of wetness index calculated from x-band radar elevation data



Wetness index was a strong predictor of soil organic C in an Iowa field

Courtesy: ER Venteris, GW McCarty, JC Ritchie, USDA-ARS, Beltsville, MD

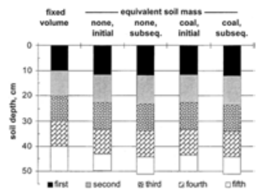
Soil organic matter affects soil bulk density and thus temporal comparisons of soil C stocks



Soil bulk density is a function of the soil mineral density and the soil organic matter content

$$\rho_b = \frac{100}{\frac{\%OM}{0.244} + \frac{100-\%OM}{\rho_m}}$$

Comparisons of soil C stocks across treatments should be done using the equivalent soil mass method

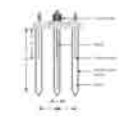


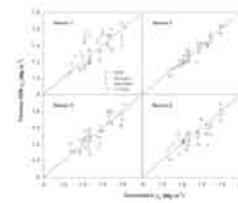
Ellert et al. (2002)

Measuring soil bulk density

- Soil core method
  - Simple and precise
  - Tedious and destructive
- Gamma ray attenuation
  - Rapid and nondestructive
  - Site-specific calibration required
  - Radiation hazard
- Thermo TDR
  - In situ, direct,nondestructive, and automated
  - Relative error
    - <5% in laboratory
    - <10% in field
  - Also: soil temperature, thermal properties, soil water

Thermal TDR sensor

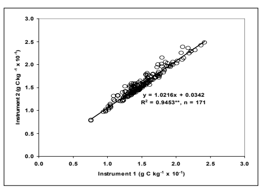




Liu et al. (2008) Soil Sci. Soc. Am. J. 72-1000-1005.

Determination of Soil C: Standard and Advanced Methods

- Standard laboratory methods
  - Wet Combustion
  - Dry Combustion
- Advanced instrumentation for field measurement
  - Laser Induced Breakdown Spectroscopy (LIBS)
  - Near Infrared / Mid Infrared Spectroscopy (NIRS / MIRS)
  - Inelastic Neutron Scattering
- Research and technology needs
  - National and international efforts needed to cross-calibrate methods against standard (soil) samples
  - Compare methods under field conditions

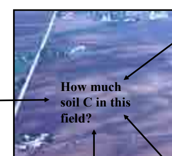


Total soil C as measured by two dry combustion instruments

Izaurralde (2005)

How can soil C be accurately be measured at the field scale?
How do emerging technologies compare against standard methods?

Standard methods: Soil sampling; wet / dry combustion



Mid / Near Infrared Spectroscopy (MIR / NIR)

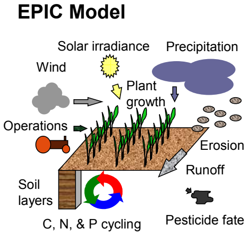
Inelastic Neutron Scattering (INS)

Laser Induced Breakdown Spectroscopy (LIBS)

USAID

EPIC: A Terrestrial Ecosystem Model built to Describe Biophysical and Biogeochemical Processes as Affected by Climate, Soil, and Management Interactions

EPIC Model



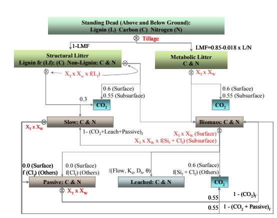
Representative EPIC modules

Williams (1995)

- Developed and maintained by USDA and Texas A&M University
- Key processes simulated
  - Weather: generated, historical, climate projections
  - Plant growth and yield
    - More than 100 plant species: crops, grasses, trees
    - Light use efficiency, photosynthetic active radiation
    - CO_2 fertilization effect
    - Plant stresses, weeds, and pests
  - Water balance: precipitation, runoff, evapotranspiration, storage, percolation
  - Simplified heat flow; soil temperature
  - Carbon cycling: net primary productivity, soil respiration, soil carbon balance, eroded carbon)
  - Nitrogen cycling: fixation, fertilization, transformation, nitrification, denitrification, volatilization, leaching
  - Erosion by wind and water
  - Plant environment control: tillage, fertilizers, irrigation, pesticides

Soil Carbon Model in EPIC

- Based on concepts and equations from Century model
- Daily time step, up to 15 soil layers
- Soil Carbon Balance
  - $\Delta SOC = C_{NPPlitter} - C_{soilrespiration} - C_{NPPharvest} - C_{erosion} - C_{leaching}$
- Carbon transformations
  - Potential
    - Temperature, water content, oxygen availability, texture, lignin, N:C ratios
  - Actual
    - N availability, demand for N
- Daily CO_2 based on actual transformations



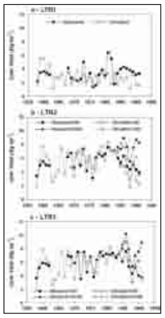
Izaurralde et al. (2006)

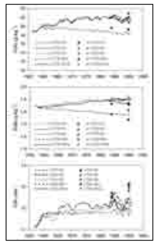
Can we simulate soil C change and sequestration rates?

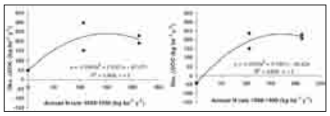
Crop yields

He et al. (2007)

Soil C, soil N and C/N ratio







Soil C sequestration rates

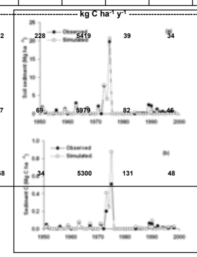
Modeling ecosystem C at watershed scale

North Appalachian Experimental Watershed (Coshocton, OH)

Annual C fluxes

	Plant C	Manure C	Respi-red C	Sedim-ent C in runoff	Soluble C in runoff	Lea-ched C
	kg C ha^{-1} y^{-1}					
W118	5702	228	5419	39	34	27
W128	5807	69	5979	82	46	22
W188	5868	34	5300	131	48	31

Sediment and C erosion in W118



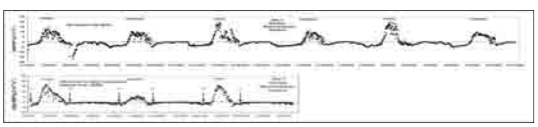
Izaurralde et al. (2007)

Simulating Net Ecosystem Productivity with EPIC using eddy covariance data from Mead, NE

- Corn-soybean rotation under no till
- Water was the main stress affecting crop yields (35 d for maize, 7 d for soybean)

		Crop Yields (Mg/ha)	
		Observed	Simulated
Maize	2001	7.2	7.0
Soybean	2002	2.9	3.5
Maize	2003	6.4	6.7
Soybean	2004	3.0	2.3
Maize	2005	7.5	7.4
Soybean	2006	3.7	3.7

Eddy covariance tower at Mead, NE

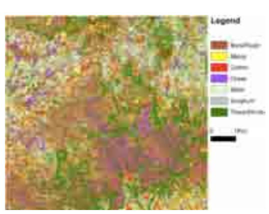


Several satellite and airborne sensors can estimate LAI, NPP, crop yields, and litter cover

- Traditional sources of land cover data:
  - AVHRR and Landsat
- Increased resolution being obtained with MODIS
- Good temporal resolution
  - MODIS and AVHRR
- Excellent spatial detail provided by
  - Landsat and SPOT
- IKONOS and Quickbird offer excellent spatial and temporal resolution
- Two airborne sensors
  - AVIRIS
  - LIDAR

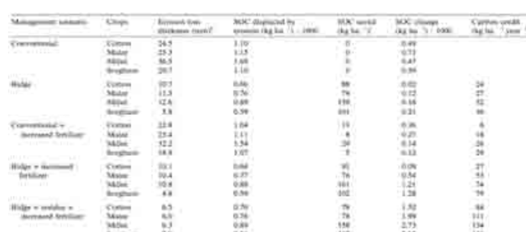
Google view and land cover classification for the Omarobougou study region in Mali

Doraiswamy et al. 2007. Agric. Systems. 94:63-74.



- The study region has an area of 64 km^2 and it is located ~50 km SE of Koutiela
- Land use classifications derived from Quickbird and SPOT images

Simulated soil C gains and losses during a 25-yr period in the Omarobougou region



Doraiswamy et al. 2007. Agric. Systems. 94:63-74.

Detecting and scaling changes in soil C by direct methods, simulation modeling, and remote sensing interpretation

- Base data
  - Land units
  - Databases
- Sampling design and data
  - Statistical power
  - Baselines
- Sampling and processing
  - Depth and depth increments
  - Bulk density
- Reporting results
  - Equivalent soil mass
- Ancillary measurements
  - Crop and biomass yields
  - Inputs and management
  - Environmental conditions
- Modeling and remote sensing
  - Models and model complexity
  - Remote sensing
    - Crop identification
    - Crop residue cover

Izaurralde and Rice (2006)