Soil Organic Carbon Measurement Protocols: A USA and Brazil comparison and recommendation

"Biogeochemical Cycles" session

PAN AMERICAN BIOFUELS AND BIOENERGY SUSTAINABILITY
AN NSF RESEARCH COORDINATION NETWORK

Recife, Brazil
July 23, 2014

Maggie Davis

Oak Ridge National Laboratory

In collaboration with Keith Kline (ORNL), Bruno Alves (EMBRAPA), Marcelo Galdos (CTBE), Douglas L. Karlen (USDA), Dana Abulebdeh (UNC-Charlotte), as well as staff from Center for BioEnergy Sustainability (CBES) and the Climate Change Science Institute (CCSI)

CBES
Center for BioEnergy Sustainability

Climate Change
SCIENCE INSTITUTE

Special thanks to Kristen Johnson and Alicia Lindauer, Alison Goss Eng, among others at the Department of Energy (DOE), BioEnergy Technologies Office (BETO)

This research was supported by the U.S. Department of Energy (DOE) Bio-Energy Technologies Office and performed at Oak Ridge National Laboratory (ORNL). Oak Ridge National Laboratory is managed by the UT-Battelle, LLC, for DOE under contract DE-AC05-00OR22725. The views in this presentation are those of the authors, who are responsible for any errors or omissions.

OAK RIDGE
National Laboratory

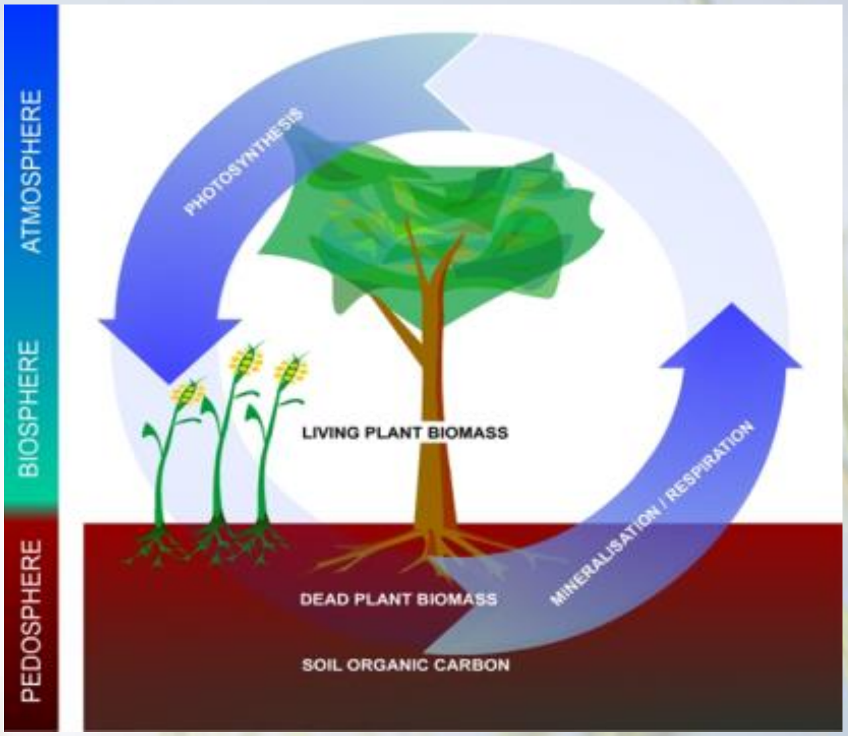
Outline

- Background: SOC importance
- Relevance
- Methods:
  - Literature review
  - Comparison
  - Analysis with co-authors
- Emerging recommendations
- Concluding remarks

Background: SOC importance

SOC:

- is a reservoir containing about two to three times more carbon than the atmosphere or vegetation.
- can significantly impact the global carbon cycle.
- reserves can be lost through inappropriate management practices such as
  - excessive tillage, drainage, or removal of plant biomass, or other disturbances.



A simplified version of the carbon cycle in vegetation and soil. Source: Steiner, Christopher 2008. Accessed from: http://www.biochar.org/joomla/index.php?option=com_content&task=view&id=67&Itemid=7&limit=1&limitstart=4

Conversely, improvements in land management (e.g., no-tillage, cover crops, forage-based rotations, etc.) that promote sequestration of SOC can simultaneously sustain or even increase SOC and contribute to the drawdown of global carbon dioxide (CO2) emissions

The performance paradox: You can’t manage what you can’t (or don’t) measure.

Source: NASA Images

Background: SOC importance

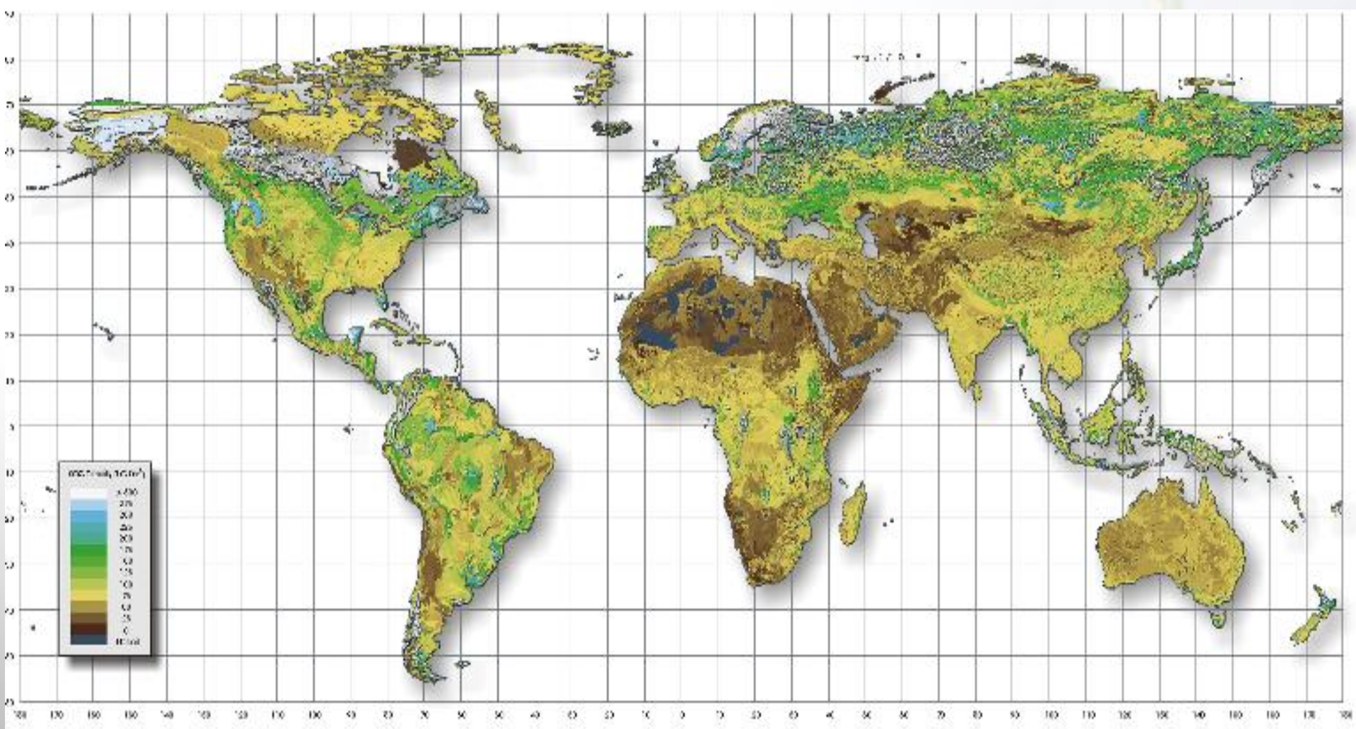
- SOC is often seen as the most important indicator of soil quality
- Measuring and understanding changes in SOC has thus become an essential activity for land managers around the world

Category	Indicator	Units
Soil quality	1. Total organic carbon (TOC)	Mg/ha
	2. Total nitrogen (N)	Mg/ha
	3. Extractable phosphorus (P)	Mg/ha
	4. Bulk density	g/cm^3
Water quality and quantity	5. Nitrate concentration in streams (and export)	concentration: mg/L; export: kg/ha/yr
	6. Total phosphorus (P) concentration in streams (and export)	concentration: mg/L; export: kg/ha/yr
	7. Suspended sediment concentration in streams (and export)	concentration: mg/L; export: kg/ha/yr
	8. Herbicide concentration in streams (and export)	concentration: mg/L; export: kg/ha/yr
	9. storm flow	L/s
	10. Minimum base flow	L/s
	11. Consumptive water use (incorporates base flow)	feedstock production: m^3/ha/day; biorefinery: m^3/day

McBride A, et al. 2011. Indicators to support environmental sustainability of bioenergy systems. Ecological Indicators 11(5) 1277-1289.

Relevance

- SOC has received significant attention from researchers and policy makers: climate change, bioenergy and bio-product industries
- Lack of consistency in measurement and verification methods



Estimates of Global Soil Organic Carbon Density from amended Harmonized World Soil Database ($t\ C\ ha^{-1}$)

HWSD data sources:
"…differences in landform, parent material, …, and time of sampling were often <u>not described explicitly in the source materials</u>."

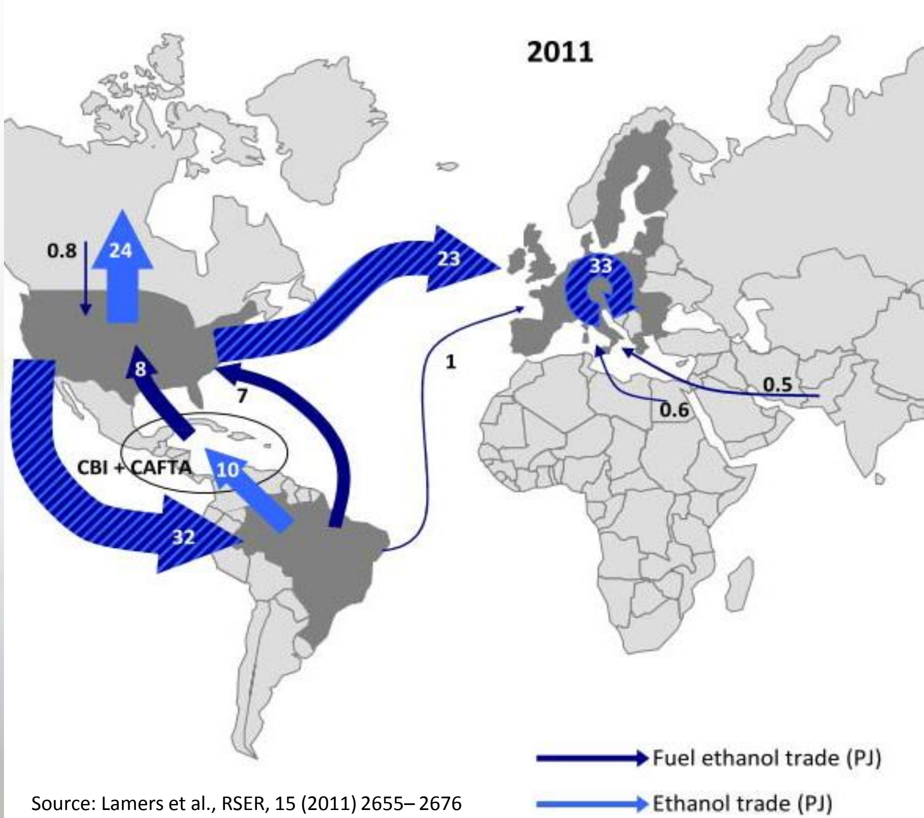
"…variables have been determined in many laboratories according to various methods and <u>these methods are not necessarily comparable..</u>."

Source: The European Commission, 2014; FAO HWSD, 2009

Relevance

US regulations (RFS2 and LCFS) require a lifecycle analysis of emissions for nearly all fuel options.

- GREET model for GHG emissions, and for estimating GHGs from land use change these include SOC emission factor:
  - estimates of emissions from a loss of SOC resulting from a change in land cover
- Bioenergy producers that can show a GHG offset for their fuel could have an advantage in the increasingly competitive global bioenergy market
- Results of lifecycle analyses are extremely important to these producers and the end users seeking the most sustainable bioenergy option

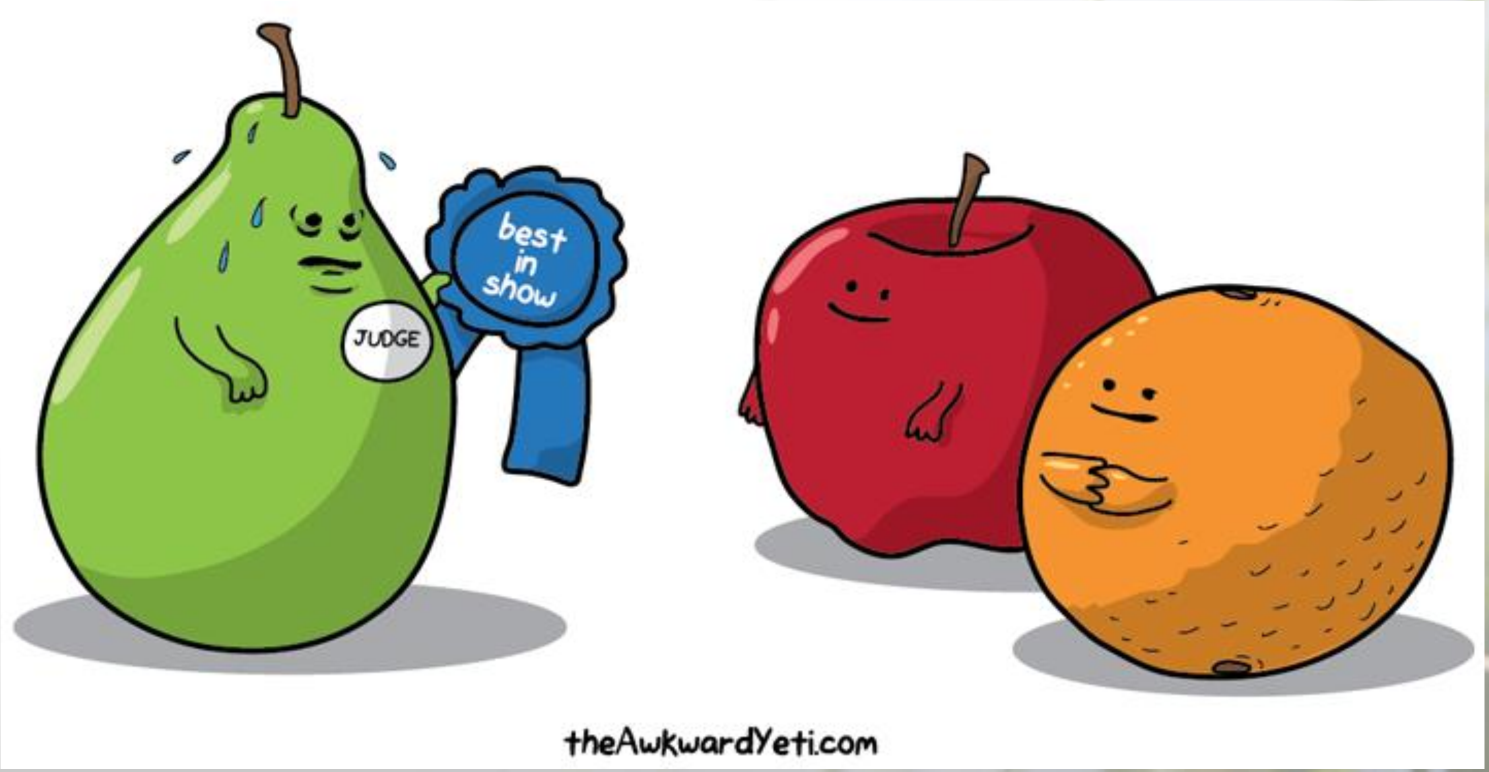


Source: Lamers et al., RSER, 15 (2011) 2655– 2676

Methods: Literature review

Bioethanol: corn in the US and sugarcane in Brazil

- focus for many sustainability assessments
- Aim is for standardized measurement protocols



Methods: Comparison, and Analysis

Table 1. Summary of reviewed studies measuring SOC for bioenergy crops, US

Author	Crop[a]	Depth (cm)	Sample Collection Method	Sample Design
Bolinder et al. (1999)	C	30	Cores	Random
Clapp et al. (2000)	C	30	Cores	Random
Wilts et al. (2004)	C/W/O	45	Cores	Random
Duiker and Lal (1999)	C/W	30	Cores	Systematic
Halvorson et al. (2005)	C/W	15.2	Cores	Random
Hooker et al. (2005)	C/W/B	15	Cores	Systematic
Motta et al. (2000)	C/S/Co/So	30	Cores	Random
Olson et al. (2005)	C/S	75	Cores	Systematic
Al-Kaisa et al. (2005)	C-S	15	Cores	Random
Varvel and Wilhelm (2010)	C/C-S/S-C	30	Cores	Random
Aziz et al. (2013)	C/C-S/W	30	Cores	Random
Evers et al. (2013)	C/S/SG	15	Cores	Random
Lee et al. (2007)	SG	90	Cores	Random
Yang and Wander (1998)	C/S	30	Cores	Random
Yang and Wander (1999)	C/S	90	Cores	Random
Rhoton et al. (2002)	C/Co	15.2	Cores	Random

OAK RIDGE National Laboratory

Methods: Comparison, and Analysis

Table 2. Summary of reviewed studies measuring SOC for bioenergy crops, Brazil

Author	Crop[a]	Depth (cm)	Sample Collection Method	Sample Design
Cerri et al. (2004)	Sc	20	Pits	Systematic
Souza et al. (2005)	Sc	30	Cores	Random
Razafimbelo et al. (2006)	Sc	10		Systematic
Resende et al. (2006)	Sc	60	Pits/auger*	Systematic
Szacks et al. (2007)	Sc	30	Pits	Systematic
Galdos et al. (2009)	Sc	100	Pits	Systematic
Pinheiro et al. (2010)	Sc	100	Pits/ auger*	Systematic
Tivet et al. (2013)	Sc	100	Pits	Random
Rossi et al. (2013)	Sc	60	Pits/ auger*	Systematic
Calegari et al. (2008)	C/S	60	Pits	Systematic
Sisti et al (2004)	S	100	Pits/ auger*	Systematic
Zotarelli et al. (2013)	C/S	100	Pits/ auger*	Systematic
Diekow et al. (2006)	C	100	Pits	Systematic

*Pits were opened for quantification of soil bulk density and samples for C analysis were from composite samples taken by auguring

Emerging results and recommendations

Position and density of sampling points

- Sampling design is crucial step & the design of an efficient, cost-effective sampling and estimation scheme is the main challenge researchers face
- Systematic and random sampling are the two types of designs used to estimate carbon stocks
  - Methodologies for carrying out these two designs are well documented (e.g., see IPCC, 2006).
- Stratified sampling not commonly used in the reviewed studies
  - Stratified random sampling and systematic random sampling are useful for within-field variability
  - high variability in soil types and within-field conditions common in many bioenergy producing areas in both the US and Brazil
  - may warrant use of the SRS technique

Emerging results and recommendations

Sampling procedures- Number of samples

- Sample design and statistically reliable results
  - Cerri et al. recommends nine trenches, covering an area of one hectare, be evaluated
  - GRACEnet are more vague
- based on available resources

Sampling procedures- Frequency and timing

- time taken for soil carbon sink (i.e. a new equilibrium) to occur is highly variable
- IPCC guidelines suggest new steady state $\geq$ 20 yr
- Sampling once restricts recognizing how SOC varies temporally
- based on available resources, other external factors

OAK RIDGE National Laboratory

Emerging results and recommendations

Sampling procedures- pits and cores

- Brazil used pits
  - For some investigations, pits were used only to take undisturbed samples for bulk density;
  - complement an increased number of samples collected using an auger
- U.S. studies generally collected soil samples with a coring device
  - GRACEnet protocol
- Emerging technology (e.g., rotary core device)

More research needed

Soil Sampling, University of Kentucky, College of Agriculture, Food, and Environment; Accessed from: http://pendleton.ca.uky.edu/sites/pendleton.ca.uky.edu/files/Soil_Sampling.jpg

Emerging results and recommendations

Sampling procedures- Sampling depth

- SOC is generally unevenly distributed over varying soil depths
- several studies show that long-term accumulation of carbon also takes place in deeper soil layers (e.g., 30-100cm)
- Variable depths in US and BR
  - Cerri et al. depth recommendations ≥ 30cm
  - GRACEnet ≥100cm
- budget or time limitations; management practices are focus

More research needed

Author	Crop[a]	Depth (cm)
Cerri et al. (2004)	Sc	20
Souza et al. (2005)	Sc	30
Razafimbelo et al. (2006)	Sc	10
Resende et al. (2006)	Sc	60
Szacks et al. (2007)	Sc	30
Galdos et al. (2009)	Sc	100
Pinheiro et al. (2010)	Sc	100
Tivet et al. (2013)	Sc	100
Rossi et al. (2013)	Sc	60
Calegari et al. (2008)	C/S	60
Sisti et al (2004)	S	100
Zotarelli et al. (2013)	C/S	100
Diekow et al. (2006)	C	100
Bolinder et al. (1999)	C	30
Clapp et al. (2000)	C	30
Wilts et al. (2004)	C/W/O	45
Duiker and Lal (1999)	C/W	30
Halvorson et al. (2005)	C/W	15.2
Hooker et al. (2005)	C/W/B	15
Motta et al. (2000)	C/S/Co/So	30
Olson et al. (2005)	C/S	75
Al-Kaisa et al. (2005)	C-S	15
Varvel and Wilhelm (2010)	C/C-S/S-C	30
Aziz et al. (2013)	C/C-S/W	30
Evers et al. (2013)	C/S/SG	15
Lee et al. (2007)	SG	90
Yang and Wander (1998)	C/S	30
Yang and Wander (1999)	C/S	90
Rhoton et al. (2002)	C/Co	15.2

Emerging results and recommendations

Sampling procedures- Sampling depth increments

- All sampling protocols emphasize the importance of sampling soil proportionately (i.e., taking samples from a constant horizontal area)
- Cerri et al. & GRACEnet protocols recommend samples to be taken in 10 cm increments throughout the soil profile
- Most of the reviewed literature used depth increments of 5 or 10 cm for the upper soil profile (30 cm)
  - depth increments >30 cm varied substantially
  - 10 to 20 cm increments in BR (in general)
  - 20 to 30 cm depth increments (in general)

More research needed

http://umbs.lsa.umich.edu/research/fest/fit/methods

Concluding remarks

More research needed in key areas

- SOC laboratory processing protocols - Bulk Density & Soil C fractionation
- Long term soil experiments
  - Management practices, baseline data and comparisons
  - Chronosequence
  - Estimating SOC over space and time

Input welcomed as we continue to develop recommendations

Thank you

davismr@ornl.gov

Thank you

Research and paper development with financial support provided by: U.S. Department of Energy, BioEnergy Technologies Office (BETO); U.S. Department of Agriculture - Agricultural Research Service; Brazilian Center of Science and Technology of Bioenergy (CTBE), Grant 2012/06933-6 from the São Paulo Research Foundation (FAPESP), NLAE, ORNL, UT-Battelle LLC,

Laboratório Nacional de Ciência e Tecnologia do Bioetanol

Special thanks to the National Science Foundation RCN project and conference organizers from Michigan Tech University.

PAN AMERICAN BIOFUELS AND BIOENERGY SUSTAINABILITY
AN NSF RESEARCH COORDINATION NETWORK

Michigan Technological University

Acknowledgements:

Co-authors from Brazil and US (Keith Kline, Dana Abulebdeh, Doug Karlen; Bruno Alves; Marcelo Galdos) as well as ORNL staff that offered advice and input; Helena Chum; Tom Wilbanks, Virginia Dale and ORNL CBES colleagues, B Davison, LM Eaton, RA Efroymson, PN Leiby, M Langholtz, LR Lynd, A McBride, GA Oladosu, ES Parish, RD Perlack, N Singh, S Kang, SB Wright, LL Wright; and DOE OBP staff Zia Haq, Kristen Johnson, Alicia Lindauer-Thompson, P Grabowski, A Goss-Eng.

CBES Center for BioEnergy Sustainability

http://www.ornl.gov/sci/ees/cbes/

Oak Ridge National Laboratory

Selected references:

- Cerri, C.E.P., Galdos, M.V., Carvalho, J.L.N.C., Feigl, B.J., Cerri, C.C., 2013. Quanitfying soil carbon stocks and greenhouse gas fluxes in the sugarcane agrosystem: point of view. Sci. Agric. **70**. 361-368.
- Doran, J.W., Jones, A.J, 1996 Editors, Methods for Assessing Soil Quality: Soil Science Society of America Special Publication **49,** SSSA, Madison, WI.
- Hansen J, Kharecha P, Sato M, Masson-Delmotte V, Ackerman F, Beerling DJ, Hearty PJ,…, Zachos JC, 2013. Assessing ''Dangerous Climate Change'': Required Reduction of Carbon Emissions to Protect Young People, Future Generations and Nature. DOI: 10.1371/journal.pone.0081648
- Houghton, R.A., 2007. Balancing the Global Carbon Budget, Annu. Rev. Earth Planet. Sci. 35:313–47. Downloaded from arjournals.annualreviews.org
- Jandl, R., Rodeghier, M., Martinex, C., Cotrufo, M.F., Bampa, F., Wesemael, B., Harrison, R.B., Guerrini, I.A., Richter jr, D.D., Rustad, L., Lorenz, K., Chabbi, A., Miglietta, F., 2014. Current status, uncertainty, and future needs in SOC monitoring. Science of the total environment **468.** 376-383.
- Kwon, H-Y, S. Mueller, J.B. Dunn, & M.M. Wander, 2013. Modeling state-level soil carbon emission factors under various scenarios for direct land use change associated with United States biofuel feedstock production. Biomass and Bioenergy 55 (2013) 299-310.
- McBride, A.C., Dale, V.H., Baskaran., L.M., Downing, M.E., Eaton, L.M., Efroymson, R.A., Garten, C.T., Kline, K.L., Jager, H.L., Mulholland, P.J., 2011. Indicators to support environmental sustainability of bioenergy systems. Ecol. Indicators **11**. 1277-1289
- Meki NM., Snider JL., Kiniry JR., Raper RL., Rocateli AC., 2013. Energy sorghum biomass harvest thresholds and tillage effects on soil organic carbon and bulk density. Industrial Crops and Products 43: 172-182.
- Olson, K.R., 2013. SOC sequestration, storage, retention and loss in U.S. croplands: Issues paper for protocol development. Geoderma **195.** 201-206.
- Panagos P, Van Liedekerke M, Jones A, Montanarella L. European Soil Data Centre: response to European policy support and public data requirements. Land Use Policy 2012;29(2):329–38.
- Reeves, PG., 1997. The roles of soil organic matter in maintain soil quality in continuous cropping systems. Soil & tillage research **43**. 131-167.
- Wang, M., Jeongwoo, H., Dunn, J.B., 2012. Well-to-wheels energy use and greenhouse gas emission of ethanol from corn, sugarcane, and cellulosic biomass for US use. Env. Research Letters **7**. DOI: 10.1088/1748-9326/7/4/045905.
- U.S Department of Agriculture, Economic Research Service using data from the USDA Production, Supply, and Distribution data base and Global Agricultural Trade System
- U.S Department of Agriculture, 2006. Model Simulation of Soil Loss, Nutrient Loss, and Change in SOC. www.nrcs.usda.gov/internet/FSE_DOCUMENTS/nrcs143_013137.pdf
- US Department of Agriculture, Natural Resources Conservation Service. NRCS, RaCA. http://www.nrcs.usda.gov/wps/portal/nrcs/detail/soils/survey/?cid=nrcs142p2_054164 Accessed 3/17/2014. Data citation: Soil Survey Staff. Rapid Assessment of U.S. Soil Carbon (RaCA) project. Available online. June 1, 2013 (FY2013 official release).

OAK RIDGE National Laboratory