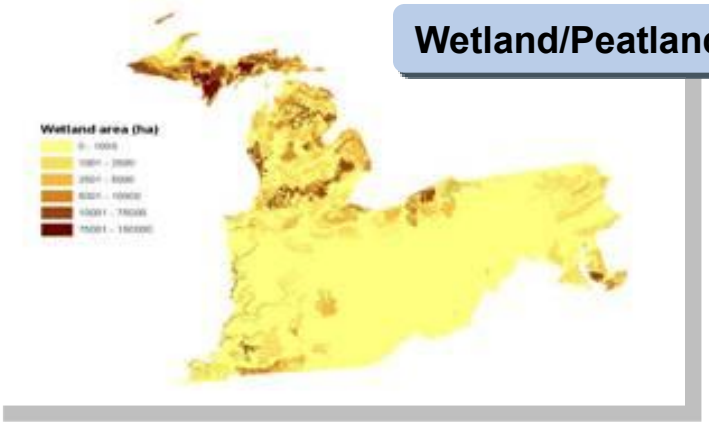
Terrestrial Sequestration Summary: Phase II Field Tests

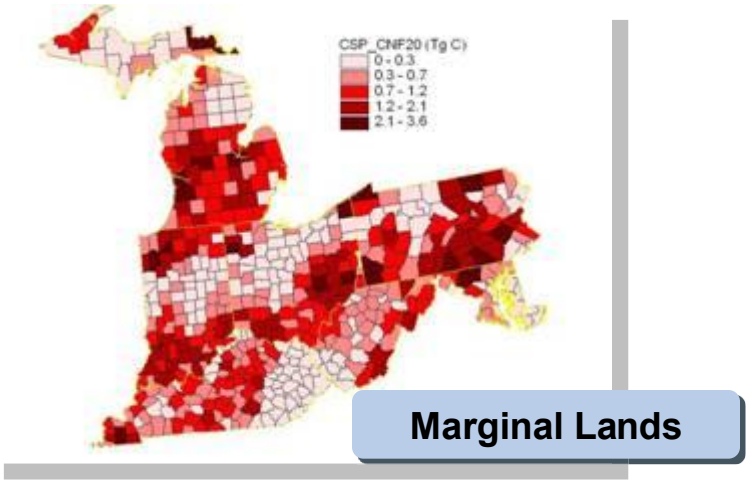
Croplands, Reclaimed Minelands & Wetlands

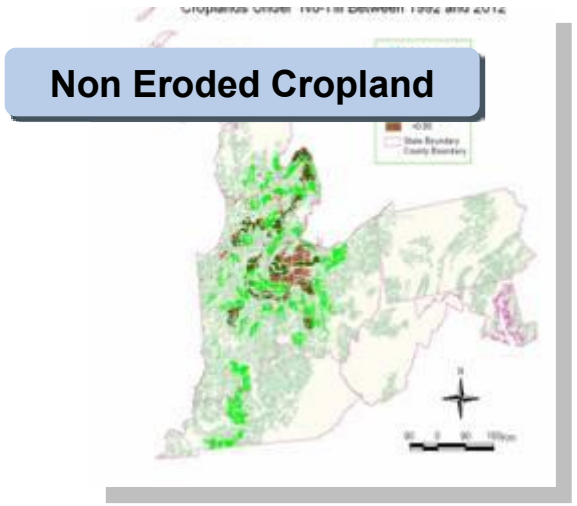
By: David Ball
MRCSP Program Manager

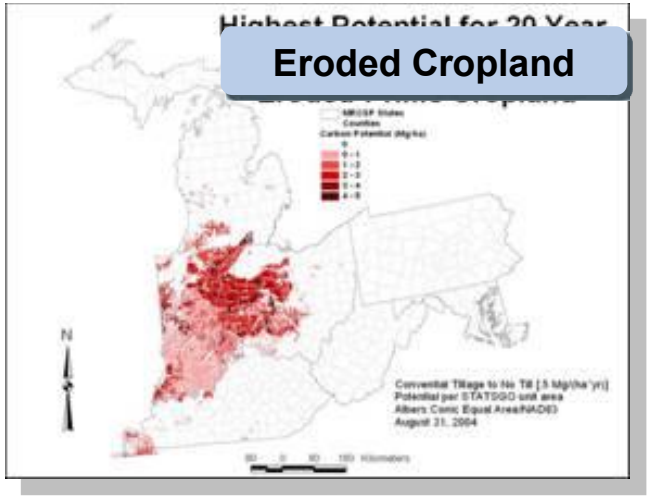
Annual RCSP Meeting, November 2009, Pittsburgh, PA

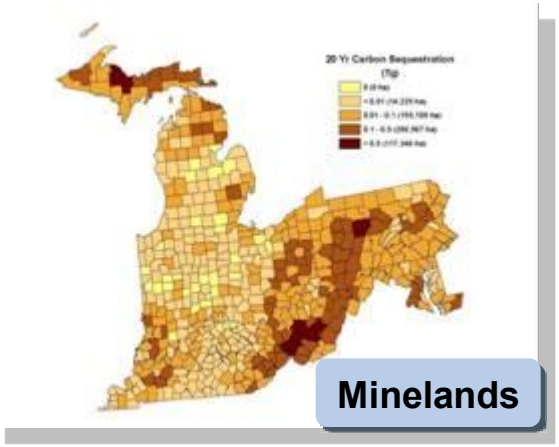
Terrestrial Sequestration Potential in the MRCSP region: approximately 150 MMt CO_2/year*





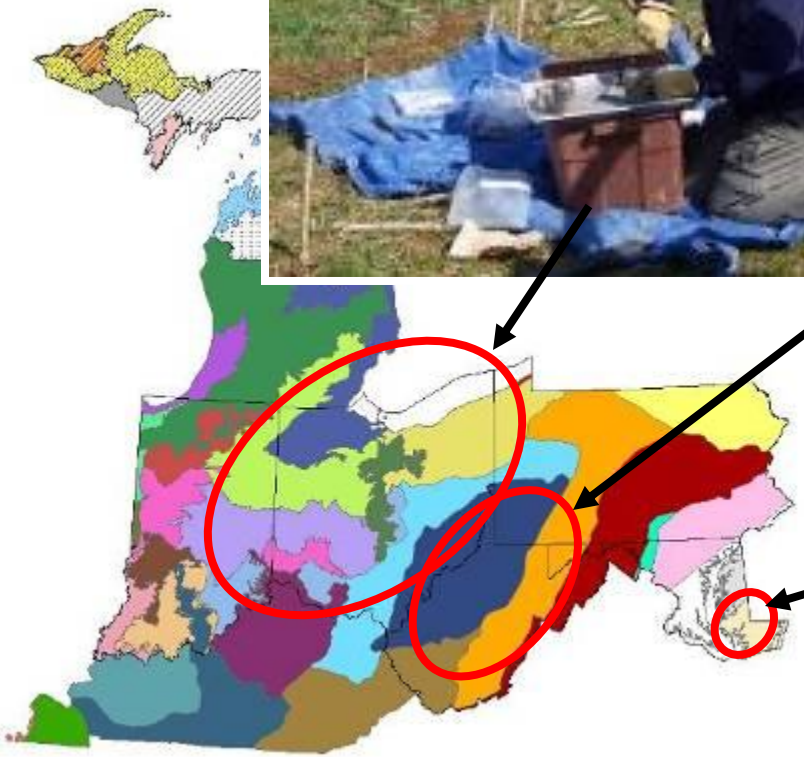






*This biophysical potential is about 18% of the CO_2 emitted annually by the region's large point sources

Three field projects were pursued under Phase II



Outline for Each Terrestrial Project

- Research Partners
- Research Goals
- Site Selection and Test Locations
- Overview of Field Testing
- Research Findings
- Best Practices
- Opportunities and Benefits

Research Partners - Croplands

Researchers:

Rattan Lal
Rajith Mukundan
Ilan Stavi

Alexandria Horne
Ryan D. Hottle
Umakant Mishra

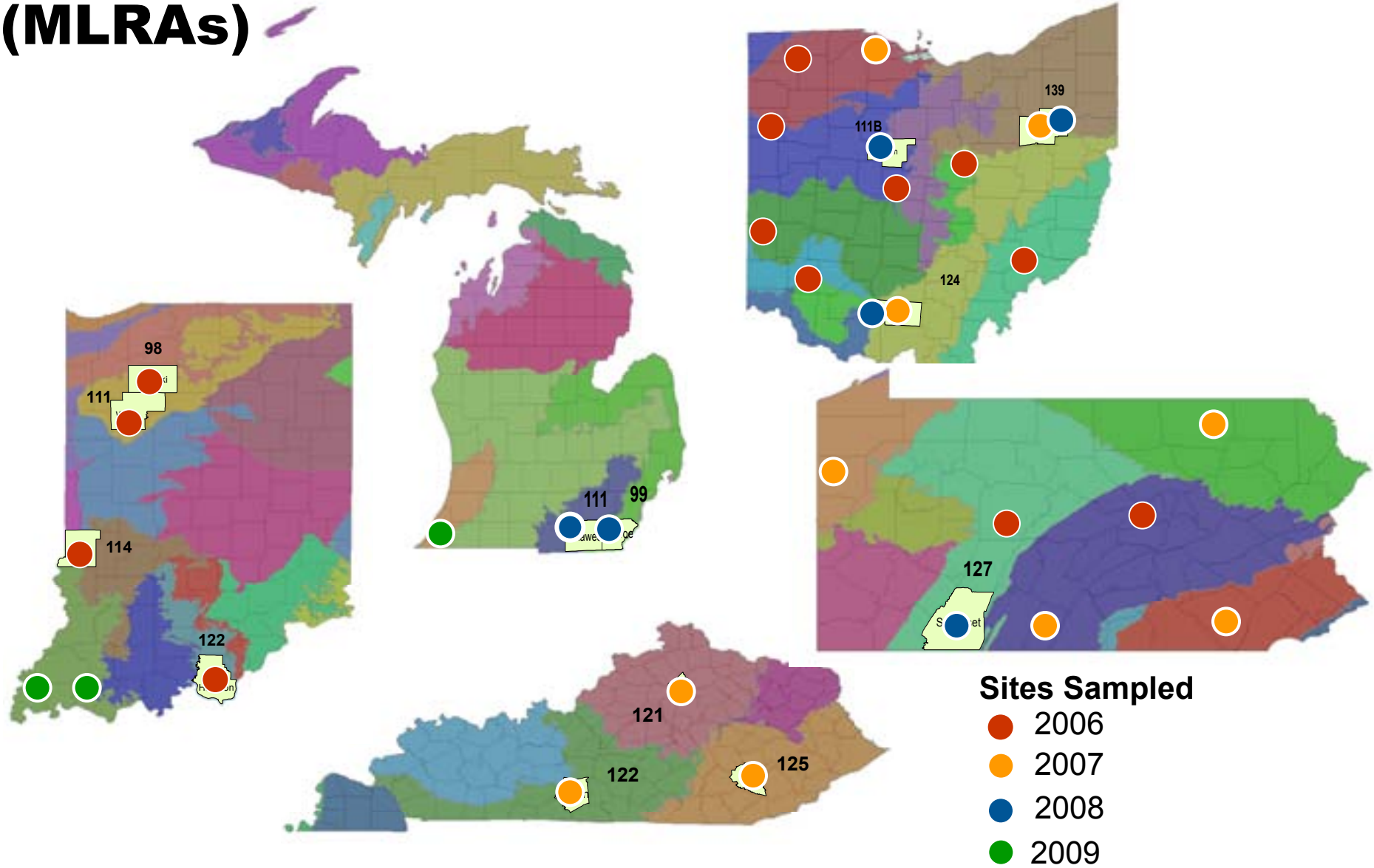
Josh Beniston
Humberto Blanco-Canqui
Amit Chatterjee

Contact: Rattan Lal, Ohio State University, (614) 292-9069, lal.1@osu.edu

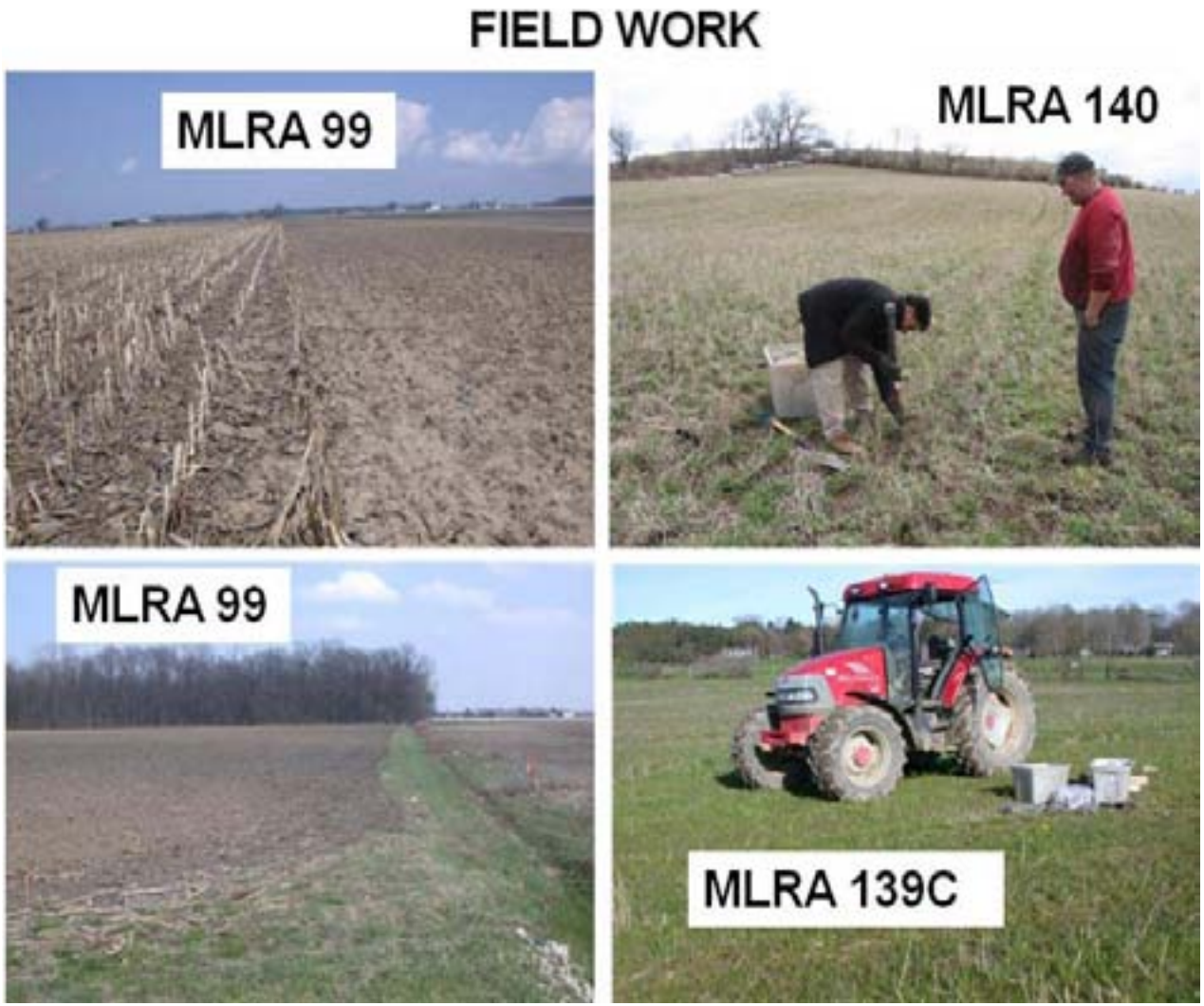
Research Goals - Croplands

- Assess sequestration potential of conservation tillage under on-farm conditions
- Quantify soil quality and the rate and magnitude of soil carbon sequestration
- Develop modeling technique to predict soil carbon pool at regional scale;
- Establish statistical and cause-effect relationship between changes in soil quality and agricultural practices;
- Identify future, innovative and emerging technologies which may enhance the technical potential of sequestration in croplands
- Integrate scientific understanding within policy framework and identify strategies for entering emerging carbon markets.

Croplands: Over 30 sampling Sites in Various Major Land Resource Areas (MLRAs)



Croplands test site examples



Tillage Systems

Conventional till

Reduced till

No-Till

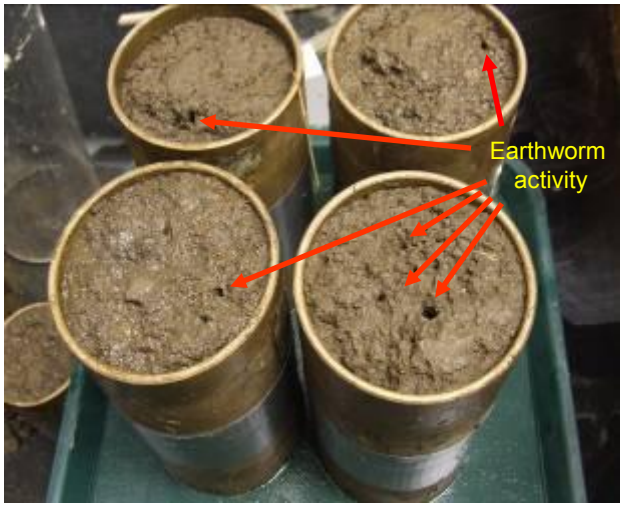
Conservation till affects:

- *Soil bulk density*
- *Biological activity*
- *Availability of resources*
- *Soil structure formation and stability*
- *Water overland flow and soil erosion*
- *Soil organic carbon (SOC) stock*
- *Crop yields*

Croplaqnds: Methodology Overview

- Samples collected from five depths: 0-5 cm, 5-10 cm, 10-30 cm, 30-50 cm, and >50 cm) in four replications 100 m apart.
- Samples analyzed for total SOC, total nitrogen (N), and various soil physical quality parameters (moisture content, soil bulk density, soil compaction, etc.).
- A complete range of field and laboratory studies have been conducted to assess the impact of soil carbon pool on soil quality and the attendant co-benefits.

CN analyzer, for analyzing soil organic carbon and total nitrogen (above)



Earth Worm Activity (above)

Croplands: Research Findings

- Residue retention as surface mulch is essential for soil carbon sequestration and soil quality improvement in no-till system.
- Rates of sequestration were 0.25-1.0 tonnes C/ha/yr (0.9 to 3.66 tonnes of CO_2/ha/yr)
- Rate depends on
  - soil properties,
  - crop rotations,
  - residue management,
  - soil fertility management, and
  - the duration since conversion from plow tillage to no-till.
- The soil carbon pool in relation to land-use and management must be measured to 1-m or at least 0.5 m depth.
  - Shallower measurements may overestimate the sequestration potential of no-till.

Research Findings Cont.

- Complete life cycle analysis of production system (i.e., no-till, plow tillage, manuring) must be conducted to assess management-induced changes,
  - essential to developing an effective mechanism for trading carbon credits.
- Residence time of carbon sequestered in soil depends on soil properties
  - more for clayey than sandy soils,
  - depth (longer for sub-soil than surface soil),
  - land use (longer for perennials than annuals)
  - management. The soil C pool is maintained or enhanced as long as no-till system and other best management practices are used.
- Soil quality is improved with increase in soil organic carbon pool;
  - practices that increase soil C also increase agronomic productivity.
- The soil C pool at regional scale can be reliably predicted by using GIS and terrain characteristics and other modeling techniques.
- Scaling up site data to a regional context is extremely useful in assessing carbon credits for trading purposes.

Best Practices to Enhance Sequestration

- No-till and conservation tillage; cover cropping; perennial crops; intensive-grazing pasture management; and restoration of marginal farmland back to prairie
- Studies by MRCSP have consistently shown that large improvements are made with regard to sequestration when crop residues are used with no-till and conservation tillage practices.

Drying and cracking of soil under conventional tillage management in Hoytville, OH.

- Impact of tillage on soil carbon and associated soil quality parameters is confined within specific soil types.

Opportunities and Benefits

- There is an estimated 10.7 million hectares of prime non-eroded cropland in the MRCSP region.
  - 22.5% of that land area is already practicing no till.
  - Remaining 77.5% or 8.3 million hectares is potentially amenable to adopting no till or reduced tillage practices
    - would result in an estimated 55 to 74 million additional tonnes of carbon sequestered over a 20 year period (200 to 270 million metric tonnes of CO_2)
- Conversion of cropland to no till reduced till also yields benefits of placing land use in more sustainable agricultural practice.
- Carbon offsets can generate income for farmers, especially as carbon markets develop.
- This Phase II research provides valuable groundwork for helping to quantify the amount of carbon stored in soils typical of the MRCSP region.

Published Papers, Croplands

- Beniston, J., Lal, R., C Sequestration in Created Prairie Landscapes In the Ohio Valley. (in progress)
- Blanco-Canqui, H. and Lal, R., 2008. No-tillage and soil-profile carbon sequestration: An on-farm assessment. Soil Science Society of America Journal, 72(3): 693-701.
- Blanco-Canqui, H.; Lal, R.; Owens, L. B.; Post, W. M.; Izaurralde, R. C. 2005. Strength properties and organic carbon of soils in the North Appalachian region. *Soil Science Society of America Journal*. Vol. 69, no. 3: 663-673.
- Blanco-Canqui, Humberto; Lal, R. 2007. Impacts of long-term wheat straw management on soil hydraulic properties under no-tillage. *Soil Science Society of America Journal*. Vol. 71, no. 4: 1166-1173.
- Blanco-Canqui, Humberto; Lal, R. 2007. Soil and crop response to harvesting corn residues for biofuel production. *Geoderma*. Vol. 141, no. 3-4: 355-362.
- Blanco-Canqui, Humberto; Lal, R. 2007. Soil structure and organic carbon relationships following 10 years of wheat straw management in no-till. *Soil & Tillage Research*. Vol. 95, no. 1-2: 240-254.
- Blanco-Canqui, Humberto; Lal, R.; Owens, L. B.; Post, W. M.; Izaurralde, R. C. 2005. Mechanical properties and organic carbon of soil aggregates in the northern Appalachians. *Soil Science Society of America Journal*. Vol. 69, no. 5: 1472-1481.
- Blanco-Canqui, Humberto; Lal, R.; Post, W. M.; Izaurralde, R. C.; Owens, L. B. 2006. Corn stover impacts on near-surface soil properties of no-till corn in Ohio. *Soil Science Society of America Journal*. Vol. 70, no. 1: 266-278.
- Blanco-Canqui, Humberto; Lal, R.; Post, W. M.; Izaurralde, R. C.; Shipitalo, M. J. 2006. Organic carbon influences on soil particle density and rheological properties. *Soil Science Society of America Journal*. Vol. 70, no. 4: 1407-1414.
- Blanco-Canqui, Humberto; Lal, R.; Post, W. M.; Izaurralde, R. C.; Shipitalo, M. J. 2007. Soil hydraulic properties influenced by corn stover removal from no-till corn in Ohio. *Soil & Tillage Research*. Vol. 92, no. 1-2: 144-155.
- Blanco-Canqui, Humberto; Lal, R.; Post, W. M.; Owens, L. B. 2006. Changes in long-term no-till corn growth and yield under different rates of stover mulch. *Agronomy Journal*. Vol. 98, no. 4: 1128-1136.
- Blanco-Canqui, Humberto; Lal, R.; Sartori, F.; Miller, R. O. 2007. Changes in organic carbon and physical properties of soil aggregates under fiber farming. *Soil Science*. Vol. 172, no. 7: 553-564.
- Blanco-Canqui, Humberto; Lal, R.; Shipitalo, M. J. 2007. Aggregate disintegration and wettability for long-term management systems in the northern Appalachians. *Soil Science Society of America Journal*. Vol. 71, no. 3: 759-765.
- Blanco-Canqui, Humerto; Lal, R.; Post, W. M.; Izaurralde, R. C.; Owens, L. B. 2006. Rapid changes in soil carbon and structural properties due to stover removal from no-till corn plots. *Soil Science*. Vol. 171, no. 6: 468-482.
- Chatterjee, A., Lal, R., 2009. On farm assessment of tillage impact on soil carbon and associated soil quality Parameters. Soil Till. Res. 104, 270-277.
- Christopher, S., Lal, R. and Mishra, U., 2009. Regional Study of No-Till Effects on Carbon Sequestration in the Midwestern United States. Soil Science Society of America Journal, 73(1): 207-216.
- Christopher, S.F., Lal, R., 2007. Nitrogen Management Affects Carbon Sequestration in North American Cropland Soils. Crit. Rev. Plant Sci. 26, 45-64.

Published Papers, Croplands (Con'd)

- Christopher, SF., Lal, R., Mishra, U., 2009. Regional Study of No-Till Effects on Carbon Sequestration in the Midwestern United States. Soil Sci. Soc. Am. J. 73, 207-216.
- Duiker, S. and Lal, R., 2000. Carbon budget study using CO2 flux measurements from a no till system in central Ohio. Soil & Tillage Research, 54(1-2): 21-30.
- Horne, A., Lal, R., Comparison of Soil Carbon Sequestration Based on Tillage Type in the MRCSP Area. (in progress)
- Izaurralde, R. C.; Williams, J. R.; Post, W. M.; Thomson, A. M.; McGill, W. B.; Owens, L. B.; Lal, R. 2007. Long-term modeling of soil C erosion and sequestration at the small watershed scale. *Climatic Change*. Vol. 80, no. 1-2: 73-90.
- Jacinthe, P. and Lal, R., 2001. A mass balance approach to assess carbon dioxide evolution during erosional events. Land Degradation & Development, 12(4): 329-339.
- Mishra, U., Lal, R., Slater, B., Calhon, F., Liu, D., Meirvenne, M.V. 2009. Predicting Soil Organic Carbon Stock Using Profile Depth Distribution Functions and Ordinary Kriging. Soil Sci. Soc. Am. J. 73, 614-621.
- Mishra, U., Lal, R., Slater, B., Calhoun, F., Liu, D. and Meirvenne, M. V., 2009. Predicting Soil Organic Carbon Stock Using Profile Depth Distribution Functions and Ordinary Kriging. Soil Science Society of America Journal, 73(2): 614-621.
- Puget, P.; Lal, R. 2005. Soil organic carbon and nitrogen in a Mollisol in central Ohio as affected by tillage and land use. *Soil & Tillage Research*. Vol. 80, no. 1-2: 201-213.
- Puget, P.; Lal, R.; Izaurralde, C.; Post, M.; Owens, L. 2005. Stock and distribution of total and corn-derived soil organic carbon in aggregate and primary particle fractions for different land use and soil management practices. *Soil Science*. Vol. 170, no. 4: 256-279.
- Saroa, G. S.; Lal, R. 2004. Mulching effects on phosphorus and sulfur concentrations in a miamian soil in Central Ohio, Usa. *Land Degradation & Development*. Vol. 15, no. 4: 351-365.
- Stavi, I., Lal, R., Owens, L.B., (a). Effects of Cattle Grazing During the Dormant Season on Soil Quality. (submitted)
- Stavi, I., Lal, R., Owens, L.B., (b). Effects of Continuous No-till and Rotational Till No-till Practices on Soil Physical Characteristics in Eastern Ohio. (submitted)
- Stavi, I., Lal, R., Soil Physical Quality and Erodibility of Water-Eroded Cropland. (submitted)
- Tan, Z. and Lal, R., 2005. Carbon sequestration potential estimates with changes in land use and tillage practice in Ohio, USA. Agriculture, Ecosystems and Environment, 111(1-4): 140-152.
- Tan, Z. X.; Lal, R.; Izaurralde, R. C.; Post, W. M. 2004. Biochemically protected soil organic carbon at the north Appalachian experimental watershed. *Soil Science*. Vol. 169, no. 6: 423-433.
- Tan, Z. X.; Lal, R.; Smeck, N. E.; Calhoun, F. G. 2004. Relationships between surface soil organic carbon pool and site variables. *Geoderma*. Vol. 121, no. 3-4: 187-195.

Research Partners – Reclaimed Minelands

Researchers:

Mark Sperow
Louis M. McDonald
Sriroop Chaudhuri
Christopher Bouquot

Contact: Mark Sperow, (304) 293-4832 , ext. 4475, Mark.Sperow@mail.wvu.edu

Research Goals – Reclaimed Minelands

With proper reclamation and sufficient time, soils degraded from mining activities have the potential to return to functioning soils, primarily by increasing the soil organic carbon content (SOC).

- The first objective of this project was to estimate the amount of soil carbon that may be stored over time in mine sites reclaimed to grass/pasture.

- A second objective was to derive the economic value of stored carbon by analyzing the tradeoff between existing land management activities (i.e., reclaiming to grass) to those that enhance carbon sequestration (i.e., reclaiming to forest).

Site Selection and Test Locations

- 5 sites were identified in Monongalia County, WV, in 2006
  - Same or similar pre-mining land use, mined coal seam, mining and reclamation methods, and overburden geology
  - Reclamation age ranged from 0 to 21 yrs.
  - The sites were reclaimed according Surface Mining Control and Reclamation Act (1977) guidelines.

Site Name	Mylan Park	WVSK	Dent's Run[1]	New Hill	WV01
Mining Begins	1982	1996	1999	2003	2004
Mining Ends	1985	1998[2]	2000	2005	2006
Mine Soil Age (in 2006)	21	3	6	1	0
Pre Mine Land use	---------- Mixed Pasture and Forest ----------				
Coal Seam	---------- Waynesburg ----------				
Method of Mining	---------- Contour Mining, Front end loaders ----------				
Overburden Type	---------- 70-80% Sandstone, rest is shale ----------				
Reclamation Method	--------- Backfilled, 7.6 cm" topsoil, grass and legumes -------				

(1) After soil sampling in 2006, the property owner stopped allowing access to the site.
(2) Site had been recontoured in 2003 and thus was actually only three years old.

Site example and sampling method

Mineland Prepared for Reclaiming

Mine Reclamation Site
(Circles identify sampling points)

Soil samples were collected at two depths (0-6 cm and 6-12 cm) using a 12.5 cm diameter auger.

Overview

- Measured soil carbon content of soil samples collected from five mine sites reclaimed in different years to assess soil carbon stocks.
  - Results used to calculate the annual rate of change of soil carbon. (1,105 soil samples were collected from the five sites over 3 years.)

- Carbon accumulation estimates from biophysical models of forest productivity were combined with the measured soil carbon data from field sites for economic analysis.

- Data for the costs of reclamation activities to grass/pasture and to forest were collected or estimated and used to derive the market value of the stored carbon.
  - Information used to determine the economic feasibility of adopting mine land reclamation activities that enhance soil carbon sequestration.

Research Findings

- Carbon accumulates in mined land reclaimed to pasture/grass, but the variability of SOC accumulation across sites is significant.
- One key finding: the number of soil samples required to adequately characterize SOC accumulation in the heterogenic soils found on reclaimed mine land is high.
  - This heterogeneity increases the cost of soil sampling, and would make verification under a carbon trading scheme more costly.
- The average rate of SOC accumulation in the MRCSP study sites in the 0 – 12 cm depth is 1.8 tonnes C ha^{-1} yr^{-1} (6.6 tonnes CO_2 ha^{-1} yr^{-1})
  - Range 0.0 to 3 tonnes C ha^{-1} yr^{-1} -- 0 to 11.1 tonnes CO_2 ha^{-1} yr^{-1}.
- Assuming average rates of SOC accumulation attained in the study sites are achieved in all reclaimed mine sites in the U.S. provides potential SOC storage of 3.2 Mt C yr^{-1} (11.8 Mt CO_2 yr^{-1}).
- If the highest SOC sequestration rate is applied, reclaimed mine land may store up to 5.4 Mt C yr^{-1} (19.9 Mt CO_2 yr^{-1}).

Research Findings (Continued)

- Reclaimed mineland planted to forest enhances carbon sequestration significantly due to carbon accumulation in aboveground biomass, litter layer, and soils.
- Marketable CO_2 amounts that could occur under the EU-ETS CO_2 market system and the CCX carbon trading scheme were estimated.
- Reclamation cost depends upon the specific costs to re-contour, vegetate, fertilize, etc., which varies by region and planting density.
- Reclamation costs using the Forest Reclamation Approach (FRA) would actually be lower in some regions compared to reclaiming to pasture because less compaction is required.

Compacted soils

Non-compacted soils

Photos courtesy of Paul Crosby Emerson, WVU [2008].

Reclaimed Minelands: Best Practices to Quantify Carbon Sequestration

Preliminary Assessment and Screening of Candidate Sites accounted for the predominant characteristics that influence changes in SOC accumulation: pre-mining land use, mined coal seam, overburden geology, and mining and reclamation practices. In addition, sites were selected at which the mine operator or landowner was known and permitted access.

MVA Technologies: Mine soils are not easy to sample due to the presence of rock fragments and limited depth. The heterogeneity of reclaimed mine soils increases the number of samples required for verification. Cost of soil sample analysis may range from $16 to $25 per soil sample. Alternative non-intrusive methods for measuring SOC content under development may promise to lower the cost of verifying carbon accumulation in soils, but these are not on the market yet.

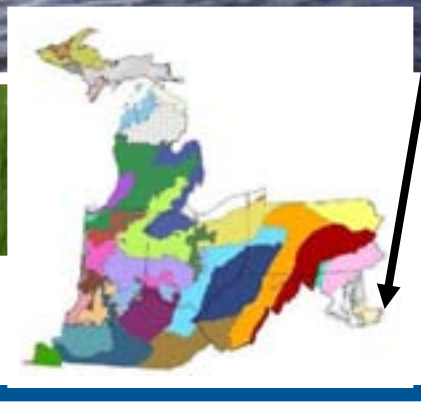
Best Practices to Enhance Sequestration

- SOC accumulation on reclaimed mine soils is dependent upon adequate top-soil replacement prior to planting the vegetative cover.
  - Mine sites with thin top soil tend to have higher rock content and accumulate SOC at a rate slower than mine sites with deeper topsoil.
- The Forest Reclamation Approach (FRA) outlined by the Appalachian Regional Reforestation Initiative (ARRI) recommends loosely graded soil and rocks and debris left on the site; thus,
  - Final grading step for forest requires less bulldozer work than the heavy compacting of the soil required for pasture.
- The FRA reclamation technique complies with the Surface Mining Control and Reclamation Act and would require 4 hours per acre less than reclaiming to pasture,
  - and could potentially save \$500 ha^{-1} in re-contouring costs.

Opportunities and Benefits

- There are 1.8 million hectares of permitted mineland in the U.S.
- The predominant mined land reclamation activity is currently to plant grass/pasture. Depending upon the market mechanisms, the SOC accumulating under pasture systems may or may not count towards CO_2 emission reduction requirements.
- The potential carbon sequestration on mineland reclaimed to forest in the MRCSP region represents a small portion of the total CO_2 emission reduction that may be required for the region.
- Reclaimed minelands could offset 4 to 8.6% of the emission reduction required by Kyoto (7% below the 1990 CO_2 emission level).
- While the CO_2 emission offset offered by reclaimed mineland is small, it may represent one of the lower cost options for offsetting emissions.
- Other benefits for reclaiming mined land to forests:
  - enhances wildlife habitat,
  - provides recreational opportunities,
  - controls soil erosion, and
  - potential future timber revenue.

Research Partners – Wetlands



Researchers:

Brian A. Needelman
Martin C. Rabenhorst
Raymond R. Weil

Principal Funding:
MDNR, Power Plant Siting Project

Contact: Brian Needelman, (301) 405-8227, bneed@umd.edu

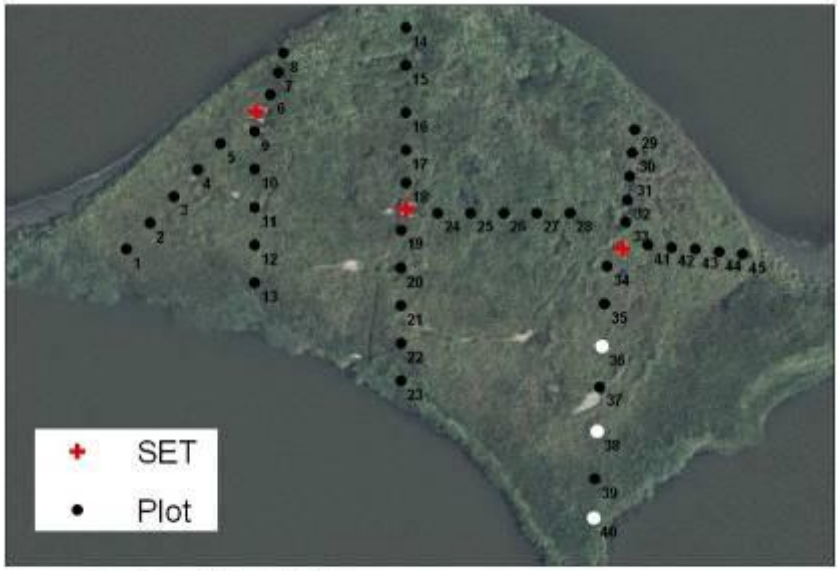
Research Goals – Wetlands

- Develop estimates of carbon sequestration rates in restored marshes over time
- Understand influence of management practices on carbon sequestration rates in restored marshes
- Improve fundamental understanding of basic processes controlling carbon sequestration in marsh soil profiles
- Develop sampling protocol for carbon sequestration validation in restored marshes

Site Selection and Test Locations

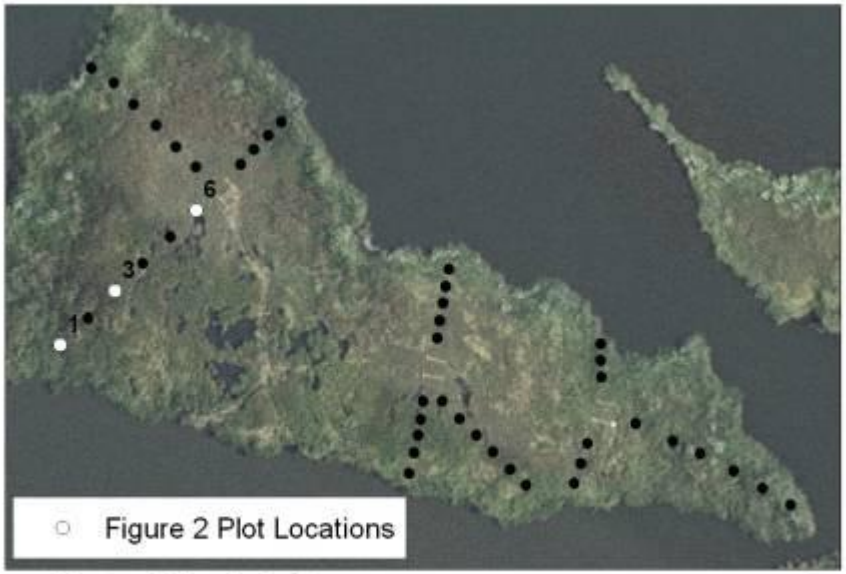
- The Army Corps of Engineers (ACE) and the U.S. Fish and Wildlife Service (USFWS) is restoring up to 20,000 acres of tidal marsh at Blackwater National Wildlife Refuge and in the surrounding mid-Chesapeake Bay region using dredged material.
- In order to test and develop restoration methods using dredged material, a tidal marsh restoration project was undertaken in 2003. Scientists are currently monitoring these sites for elevation changes and vegetation status.
- The MRCSP has facilitated outreach and data collection on carbon sequestration in order to use these sites as field validation tests for this technology.

Sampling Sites



Restored Marsh Cell Plot Locations

0 12.5 25 50 Meters



Natural Marsh Cell Plot Locations

0 12.5 25 50 Meters

- The study is being conducted on one restored tidal marsh cell created in 2003 and one natural marsh cell, both located at the Blackwater National Wildlife Refuge.
- The plot locations for annual soil core and vegetation collection are shown above.

Overview, Methodology

- Within each cell, 45 plots chosen for annual soil core and vegetation data collection.
- In addition, each marsh cell has a well and temperature probe with data logger. Data include porewater chemistry and methane emissions.
- Feldspar markers used to mark initial surfaces. Feldspar forms a bright white layer. In subsequent years, soil samples were collected above and below the initial marked surface.
- Soil cores collected using a McCauley peat auger to a depth of 50 cm and bagged in the field
  - Samples divided by horizon if apparent by the presence of the feldspar marker horizon or by 25-cm increments if horizons were not apparent
- Samples were collected in 2006, 2007, and 2008.
  - Organic carbon and total nitrogen were measured.
  - Bulk density and total carbon content were calculated for each horizon.

Research Findings

- Changes in subsurface carbon contents in tidal marsh soils were reliably quantified;
  - thus, researchers determined surficial changes and alternative methods for subsurface monitoring.
- The restored and natural marshes at the Blackwater Wildlife Refuge are sequestering carbon at an above-average rate versus the national average based solely on surficial accumulation, which is probably an underestimate.
- At the rate of 3.4 tonnes carbon ha^{-1} yr^{-1} of surficial carbon sequestration, the proposed 8,000 ha restoration would sequester about 27,000 tonnes carbon yr^{-1} (or 110,000 tonnes CO_2 yr^{-1}).
- The rate of carbon sequestration would likely vary across wetland types within the proposed restoration; however, this estimate is within the range typically found in this region. This estimate is conservative because it is only accounting for surficial carbon deposits.
- A significant portion of the carbon sequestration benefit in these marshes is offset through methane emissions.

Best Practices to Quantify Carbon Sequestration

- Marsh soils are challenging because they are highly dynamic in their volume and are continually accumulating material near the surface.
- The University of Maryland had originally planned to address this complication through the use of feldspar marker horizons in the soil profiles; however, these horizons proved to be inconsistent and were therefore not reliable.
- The proposed solution is to install an earth anchor, a metal rod with a horizontal plan at its base (similar to a screw). This would then serve as a reference plane for future sampling.
- If the soil layers become denser above this reference plane, then the samples will be collected to a shallower depth; if they loosen, then sampling will be deeper.

Opportunities and Benefits

- Current proposals by the ACE and USFWS include estimates of up to 8,000 hectares of marsh restoration in the mid-Chesapeake Bay region.
- Modeling work has estimated that the C sequestration rates in these marshes may range from 2.5 to 5.7 tonnes C ha^{-1} yr^{-1}.
  - These estimates are approximate and are highly dependent on rates of organic matter accumulation and sea-level rise.
- At these values the full restoration would sequester 20,000 to 45,600 tonnes C yr^{-1} or 75,000 to 170,000 tonnes CO_2 yr^{-1}.