2013 DOE Bioenergy Technologies Office (BETO) Project Peer Review

Second Generation Biofuels: Carbon Sequestration and Life Cycle Analysis

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Technology Area Review: Feedstock Supply & Logistics

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Project Goals

- Determine the impact of corn residue removal on soil organic carbon (SOC), water use efficiency and life cycle analysis of total greenhouse gas (GHG) emissions of crop production and cellulosic ethanol
- **BETO goal:** "Develop technologies to sustainably provide secure, reliable, and affordable cellulosic biomass supply for the U.S. bioindustry"
- **BETO goal:** "Develop cost-competitive biomass technologies to enable the production of biofuels nationwide…."

Quad Chart Overview

Timeline

- Project start: Sept. 10, 2010
- Project end: Sept. 30, 2013
- Percent complete = 75%

Barriers

- Barriers addressed
  - Ft-B. Sustainable Production
  - Ft-D. Sustainable Harvest

Budget

- Funding for FY11($154,000/$47,000)
- Funding for FY12 ($154,000/$47,000)
  Funding for FY13 ($154,000/$47,000)
- Years the project has been funded: 2.3
  Average annual funding: $206,000

Partners*

- **Collaborator:** Univ. of Nebraska, Dept of Computer Science
- **Interaction:**
  I. USDA-ARS (Lincoln, NE & Ames, IA)
  II. Novozymes
  III. Poet

*no transfer of funds

Project Overview

- Research being conducted in two production size fields (about 50 hectares/120 acres) of irrigated maize at the University of Nebraska Agricultural Research and Development Center, Mead, Nebraska

- Residue is removed from one field (~60% removal—total amount that could practically be removed using conventional bailing) and not removed in the control field

- Life cycle assessment & modeling integrates results from field studies

Approach

- **Task A:** Tower eddy covariance systems quantify landscape level CO_2 flux to estimate net annual SOC change in the two fields (g C m^{-2} yr^{-1})
- **Task B:** Evapotranspiration (mm yr^{-1}) and water use are quantified
- **Task C:** Fluxes of nitrous oxide (g N_2O-N m^{-2} yr^{-1}) and methane (g CH_4-C m^{-2} yr^{-1}) are quantified
- **Task D:** Modeling SOC dynamics to CO_2 and use of supercomputing to geospatially extrapolate site-level measurements to wider geographical areas & longer timescales, and compare with field sites
- **Task D:** Inclusion of above measurements & modeling in life cycle analysis to determine the net GHG emissions (g CO_2e MJ^{-1}) from the production of cellulosic ethanol (second generation biofuel)

Tasks A-C

Task A & B: Eddy covariance flux measurements of CO_2 and water

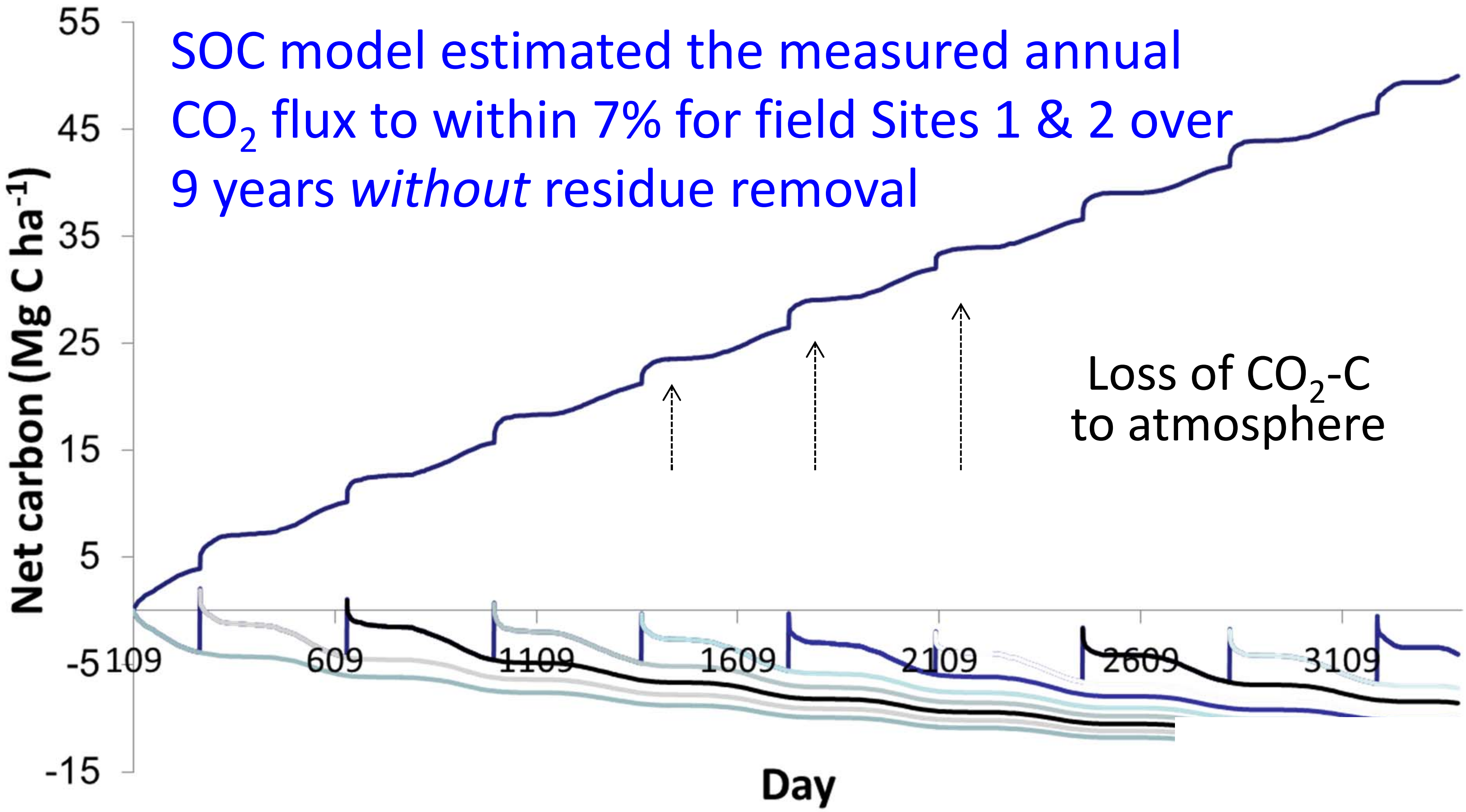
- Hailstorm in September 2010 lodged ~85% of grain at Site 1 and 50% in Site 2 which greatly increased respiration from decaying grain and reduced net ecosystem CO_2 exchange (NEE) in 2011
- Net Ecosystem Exchange (ΔC), crop yield, & evapotranspiration were each very comparable (<2%) between Sites 1 & 2 in 2012
- Removal of 174 g C m^{-2} of surface residue at Site 2 in 2012 led to the greatest source of difference in Net Biome Production (ΔC)

Task C: Static chamber measurements of N_2O & CH_4 fluxes indicate:

- Both sites are sources of N_2O (emission) and sinks of CH_4 (uptake)
- Fluxes are highly variable (CV ≥ 100%)
- N_2O fluxes contribute much more to global warming potentials than CH_4 fluxes
- Residue removal appears to decrease N_2O emissions but have little effect on CH_4 uptake

Soil modeling was used to estimate residue removal impacts on net CO_2 because of hail damage at field sites in 2011

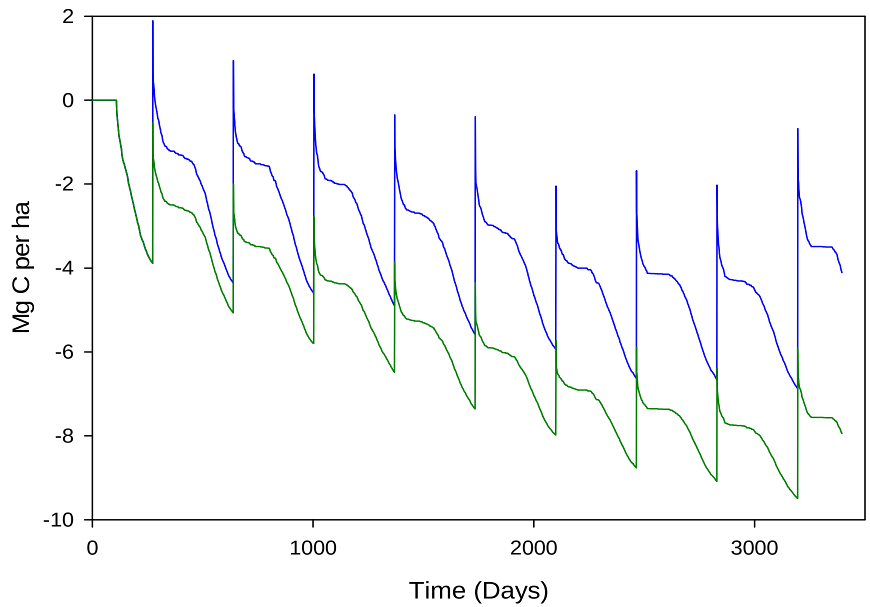
Modeled oxidation of SOC and corn residue using data on **initial SOC**, **C input from crop yield**, & **daily temperature** from 9 years of continuous corn at Mead, NE



Source: Liska et al., manuscripts in preparation; Fang 2012, Pelton 2013.

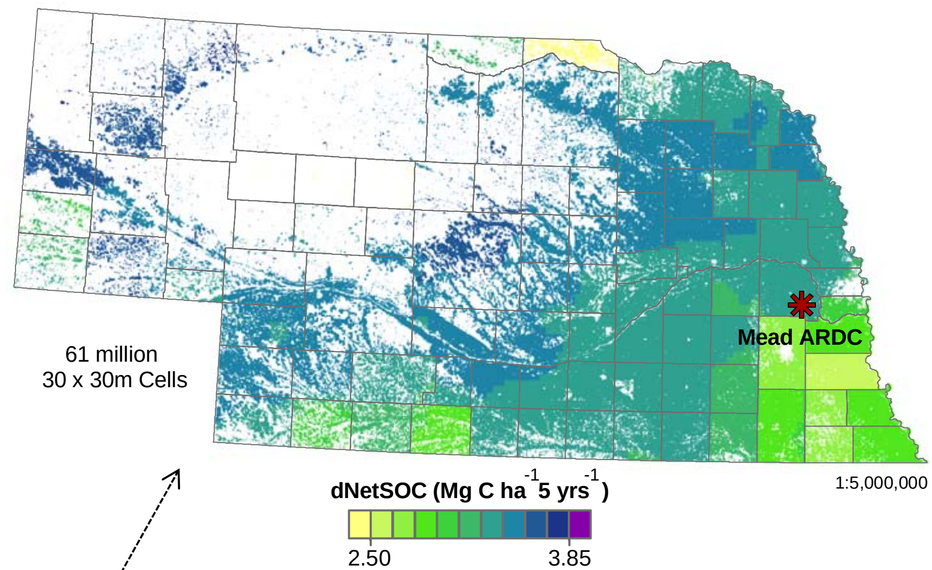
Model-estimated SOC loss from residue removal at CSP Sites 1 is similar to NE average loss using GIS & supercomputing

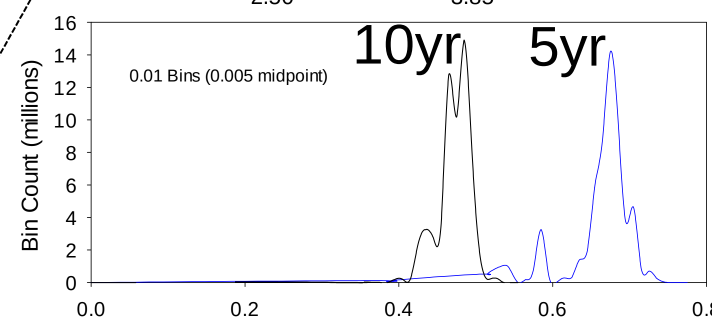
Site 1: *NET* SOC loss using site measurements and estimated 50% residue removal (green)



0.43 Mg C ha^{-1} yr^{-1}

NE: 61 million cells & >7.2 billion calculated monthly time steps across state for 10 yrs using supercomputing





0.47 Mg C ha^{-1} yr^{-1}

GIS analysis combines: SSURGO SOC, county-level crop yields (2001-10), and daily temperature (PRISM)

Source: Liska et al., manuscripts in preparation; Fang 2012, Pelton 2013.

Task D: Life Cycle Assessment of 4 Scenarios*:

NET SOC to CO_2 emissions + field production input emissions + uncertain processing emissions & credits

Biofuel system	Field emissions	Biofuel Energy yield	Field emissions	Biorefinery emissions	Life cycle	GHG reduce
	A	*B*	*C=A*1000/B*	*D*	*C + D*	
	Mg CO_2 ha^{-1} yr^{-1}	GJ ha^{-1} yr^{-1}	g CO_2e MJ^{-1}			%
No net change in SOC	0	32.4	0	10	10	89
Net oxidation of SOC to CO_2 **+ 0.43 Mg C ha^{-1} yr^{-1}**	1.58	32.4	48.8	10	58.8	38
Total net emissions: SOC loss + inputs	1.94	32.4	59.9	10	69.9	26
Total net emissions: SOC loss + inputs + electricity credit	1.94	32.4	59.9	-22	37.9	60

*Table from quarterly report, October 30, 2012.

Source: Liska, *Sustainable Biofuels*, in press; Liska et al., manuscripts in preparation;

Relevance

- "Define and validate sustainable agronomic activities specific to feedstock type and region (2007-2012)" (Multi-Year Plan 2010, 3-16)
- Apply net GHG emissions results from field experiments to *Energy Independence and Security Act 2007* regulations (EPA LCA assessments)
- Initial LCA results suggest that removal of residue will likely produce GHG emissions that exceed EPA thresholds without appropriate mitigation actions

Critical Success Factors

- *"ii. Establishment of a baseline for environmental sustainability of feedstock supply"*
- GHG emissions reduction of 60% is already set for cellulosic ethanol by the EPA
- Determine impact of residue removal for cellulosic ethanol on net GHG emissions
- Ensure the integrity of analytical approaches by publishing peer-reviewed journal articles describing the scientific methods and results

Potential Challenges

- Unfavorable weather conditions and equipment malfunction
  - Rigorous quality control procedures already implemented should minimize data gaps
  - Gaps in the eddy covariance flux data are also being routinely filled using standard Ameriflux protocols
- Outbreaks of pests and diseases
  - Employ “best management practices” prescribed for production-scale maize systems to minimize the impact
- Natural disasters (including hailstorms, tornadoes)
  - Keep an inventory of spare sensors to resume data collections as soon as feasible
- Limited data available for commercial cellulosic ethanol production efficiency for LCA

Future Work (through September 30, 2013)

- Complete nearly 3 years (2011-13) of field measurements on:
  - Tower eddy covariance fluxes of CO_2 and water vapor
  - N_2O and CH_4 fluxes using surface chambers

- Quality control and complete analysis of about 2.5 years of data on fluxes of CO_2, H_2O, N_2O and CH_4, and supporting variables

- Complete manuscript on SOC modeling and GIS supercomputing simulation of residue removal across US Corn Belt

Summary

- **Relevance**
  - SOC loss appears to add to net GHG emissions from cellulosic ethanol, but must be >60% GHG emissions reduction compared to gasoline
- **Approach**
  - Tower eddy covariance method provides year-round measurement of landscape level fluxes of CO_2 and water vapor
  - Static chamber used to quantify annual surface fluxes of N_2O & CH_4
  - Emissions and modeling results are included in LCA (EPA regulations)
- **Technical Accomplishments**
  - Work began September 10, 2010. Progress on schedule.
  - Manuscript describing theoretical structure of LCA calculations for inclusion of SOC loss is *in press*
  - Manuscript on SOC modeling and GIS analysis is *in development*
- **Success Factors & Challenges**
  - Accurate quantification of GHG emissions in extreme weather and natural disasters (e.g., hailstorms, tornadoes)

Publications, Presentations, and Commercialization

- Liska AJ. In press. *Eight Principles of Uncertainty for Life Cycle Assessment of Biofuel Systems*. Chapter 10, IN: Bhardwaj AK, Zenone T, Chen JK (eds.), ***Sustainable Biofuels: An Ecological Assessment of Future Energy***. Walter De Gruyter & Co., Berlin. http://www.degruyter.com/view/product/184110
- Karlen, DL, Archer D, Liska AJ, Meyer S. 2012. *Energy Issues Affecting Corn/Soybean Systems: Challenges for Sustainable Production*. **Council on Agricultural Science and Technology (CAST), Issue Paper 48**. Ames, Iowa.
- Fang XX, 2012. *Soil Greenhouse Gas Emissions in the Life Cycle Assessment of Cellulosic Ethanol from Crop Residue*. **MS Thesis, Environmental Engineering. University of Nebraska**
- Pelton MP, 2013. *Soil Organic Carbon Dynamics in Agriculture: Model Development and Application from Daily to Decadal Timescales*. **MS Thesis, Env. Engineering. Univ. Nebraska.**
- Liska AJ, Milner M, Goddard S, Zhu H, Yang H, Suyker A. *Spatial Soil CO_2 Emissions Modeling and LCA of Cellulosic Ethanol*. **Growing the Bioeconomy: Social, Environmental and Economic Implications**. Banff, Canada, Oct. 4, 2012.
- Liska, AJ. *Soil Carbon Loss Contributes to Greenhouse Gas Emissions from Cellulosic Ethanol*. **Agricultural Decision Making with Water and Climate Change Perspective**. Lied Conference Center, Nebraska City NE, November 1-3, 2011.
- Liska AJ. *Soil Carbon Loss Contributes to Greenhouse Gas Emissions from Cellulosic Ethanol*. **Novozymes, Copenhagen, Denmark**, May 9, 2011
- Liska AJ. *Soil Carbon Loss Contributes to Greenhouse Gas Emissions from Cellulosic Ethanol*. **University of Nebraska-Lincoln, Agronomy Seminar**, April 22, 2011
- No commercialization efforts.

Responses to 2011 Reviewers' Comments

- "*Comparison of two fields will have an inherently limited inference base*"
Reply: **SOC modeling (with state GIS modeling) ensures that measured field data are consistent with general behavior of other field studies, and that the measured field sites approximate state average trends**
- *"…residue removal is problematic from a GHG emissions perspective. Project conclusions to-date are counter to most published literature*"
Reply: **Recent publications confirm our assertion that residue removal depletes SOC and is released as CO_2** (Kutsch et al. 2010. *Soil Carbon Dynamics: An Integrated Methodology*. Cambridge U. Press; Kochsiek & Knops, 2012. *GCB Bioenergy* 4, 229–233; Cherubini & Ulgiati 2010. *Applied Energy* 87: 47–57)
- **"***A critical factor will be submitting to rigorous external peer review*."
Reply: **The LCA calculations shown above & in 2011 have been rigorously reviewed by the USDA-ARS REAP (Karlen et al. in 2011), and at least 20 hours has been spent reviewing these calculations with industry (Novozymes and Poet), 2x academic presentations to at least 70 faculty, and a peer-reviewed book chapter on the issue is in press.**

http://www1.eere.energy.gov/biomass/pdfs/2011_feedstock_review_comments.pdf