2017 CRC LIFE CYCLE ANALYSIS OF TRANSPORTATION FUELS WORKSHOP, OCT 25-26, 2017

Simulating soil carbon change of biofuel feedstocks for GREET biofuel life cycle analysis

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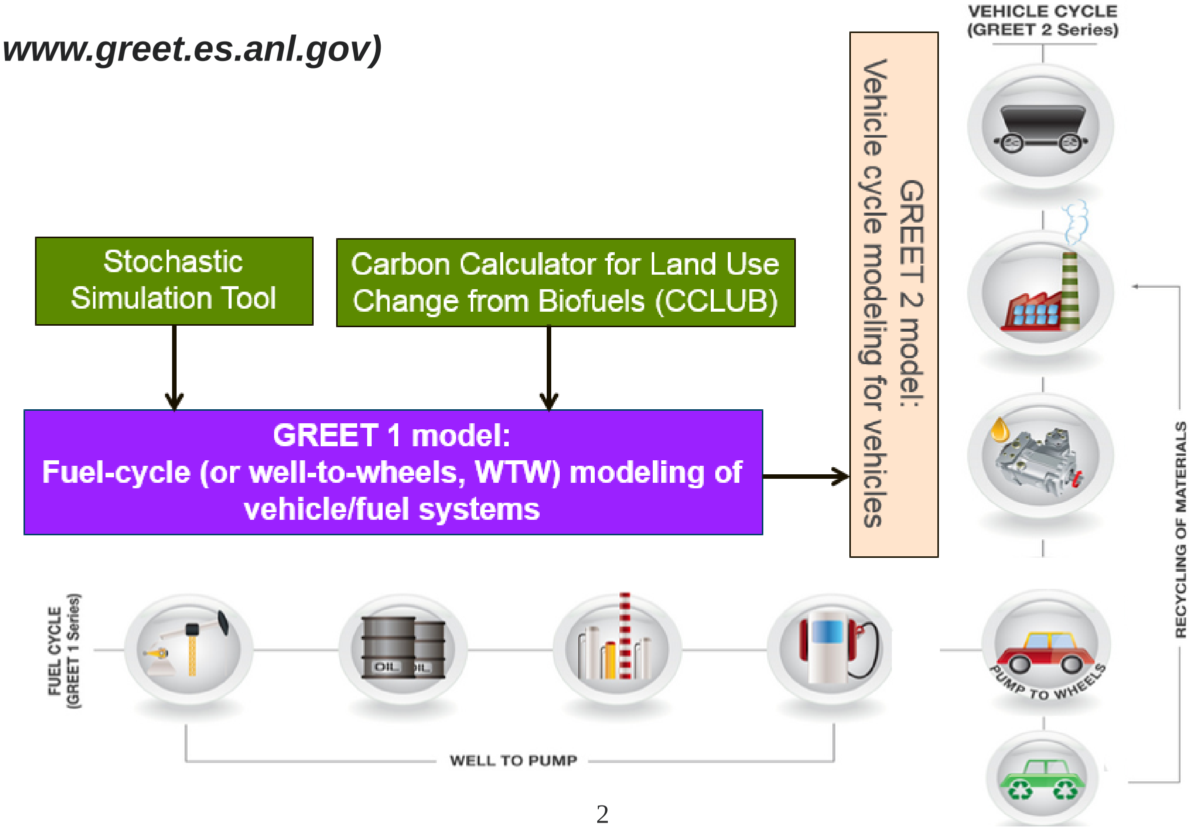
The GREET® (Greenhouse gases, Regulated Emissions, and Energy use in Transportation) model

(Available at www.greet.es.anl.gov)



GREET outputs include energy use, greenhouse gases, criteria pollutants and water consumption for vehicle and energy systems

Energy use

- Total energy: fossil energy and renewable energy
  - Fossil energy: petroleum, natural gas, and coal (they are estimated separately)
  - Renewable energy: biomass, nuclear energy, hydro-power, wind power, and solar energy

Greenhouse gases (GHGs)

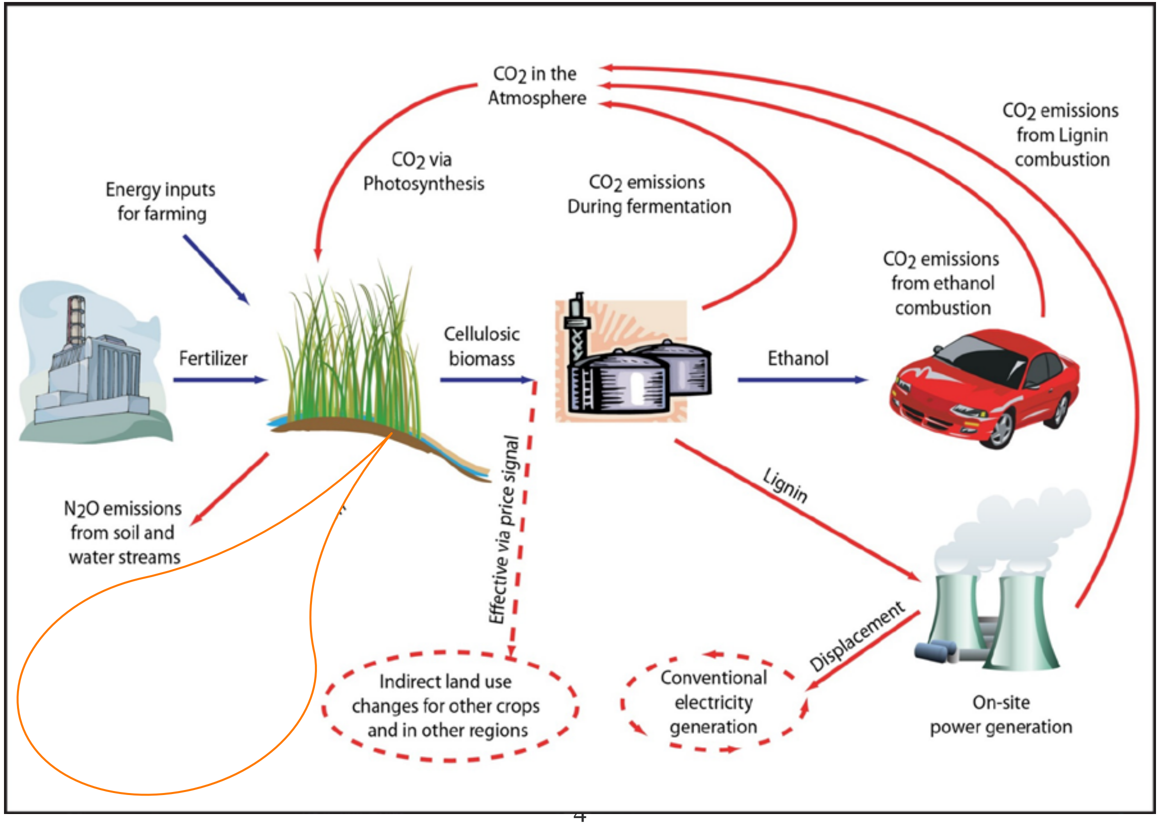
- CO_2, CH_4, N_2O, black carbon, and albedo
- CO_{2e} of the five (with their global warming potentials)

Air pollutants

- VOC, CO, NO_x, PM_{10}, $PM_{2.5}$, and SO_x
- They are estimated separately for
  - Total (emissions everywhere)
  - Urban (a subset of the total)

Water consumption

GREET System Boundary for Biofuel LCA: Direct Activities and Indirect Effects are Included



Soil?

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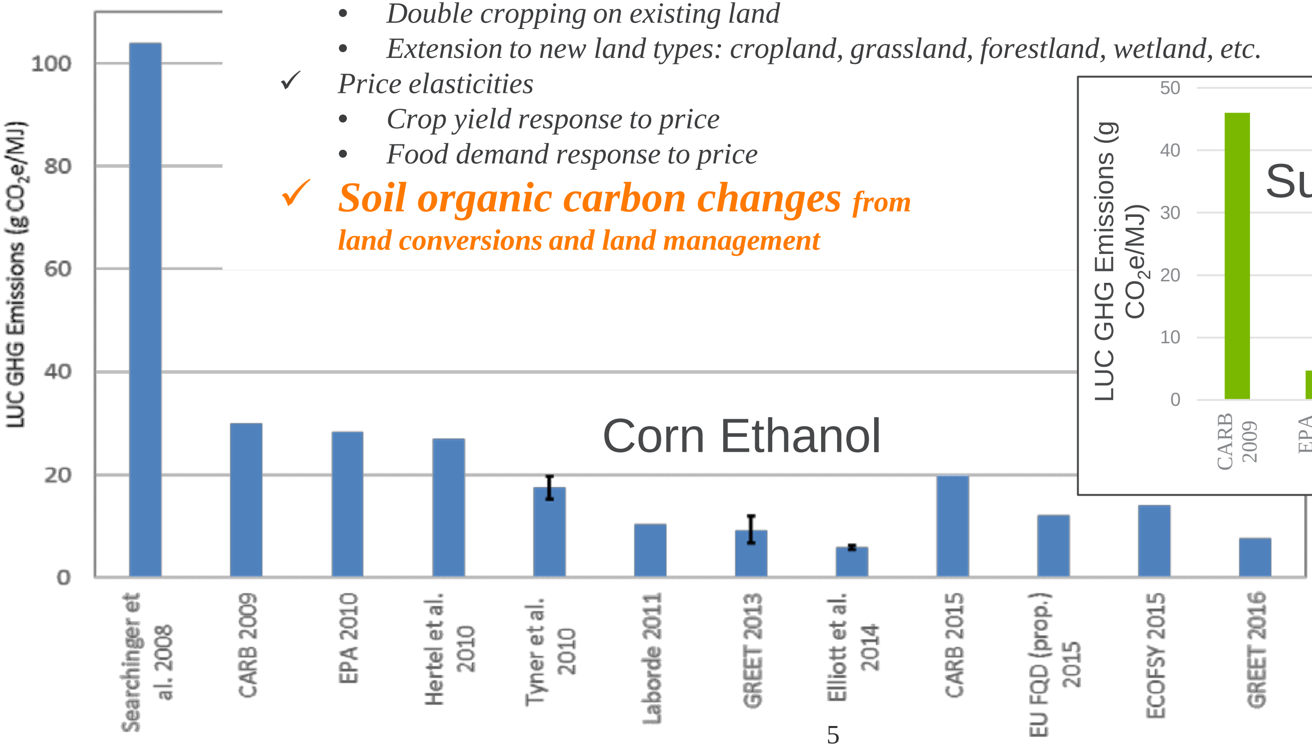
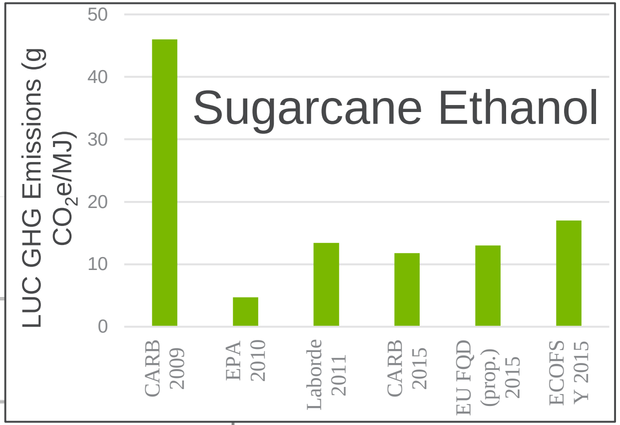
Trend of Estimated LUC GHG Emissions for Corn and Sugarcane Ethanol

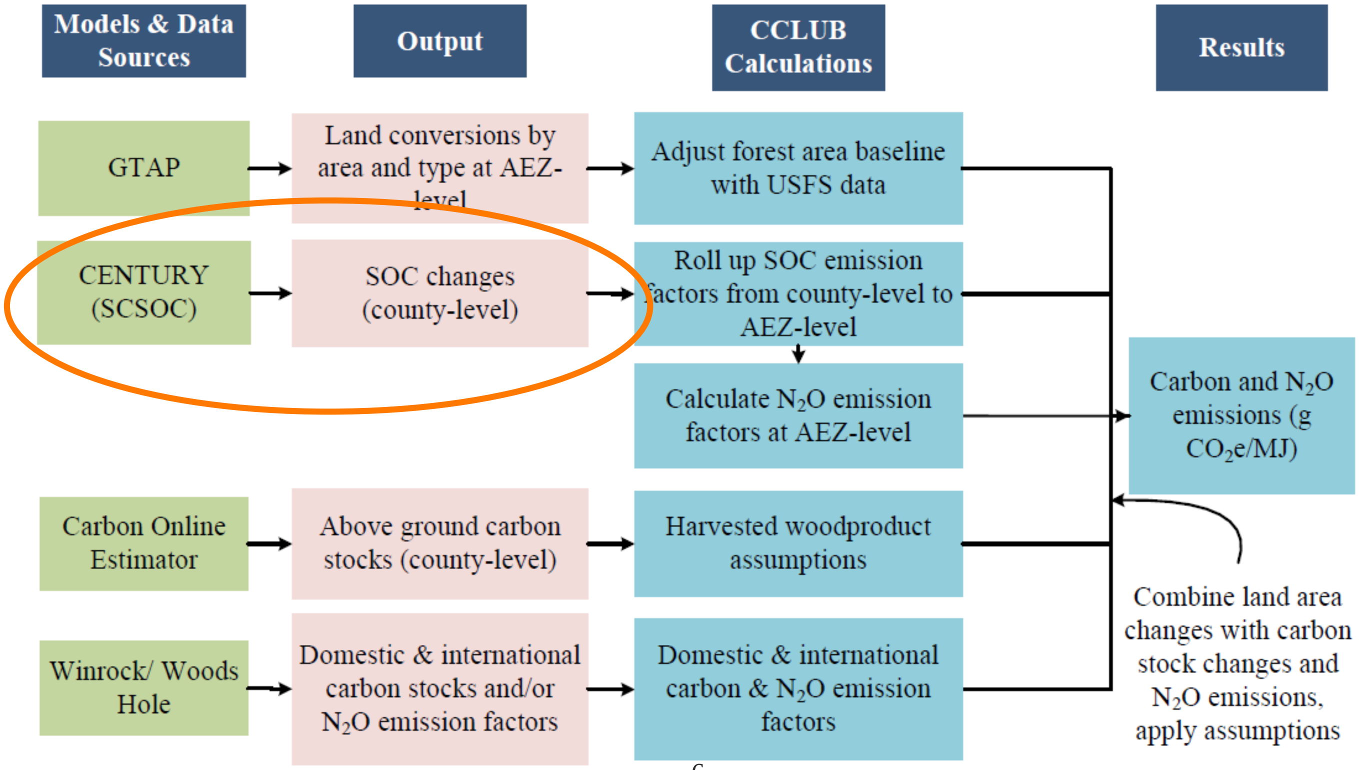
Critical factors for LUC GHG emissions:

- ✓ *Land intensification vs. extensification*
  - *Crop yields: existing cropland vs. new cropland; global yield differences and potentials*
  - *Double cropping on existing land*
  - *Extension to new land types: cropland, grassland, forestland, wetland, etc.*
- ✓ *Price elasticities*
  - *Crop yield response to price*
  - *Food demand response to price*
- ✓ ***Soil organic carbon changes from land conversions and land management***





Carbon Calculator for Land Use Change from Biofuels (CCLUB) Module in GREET



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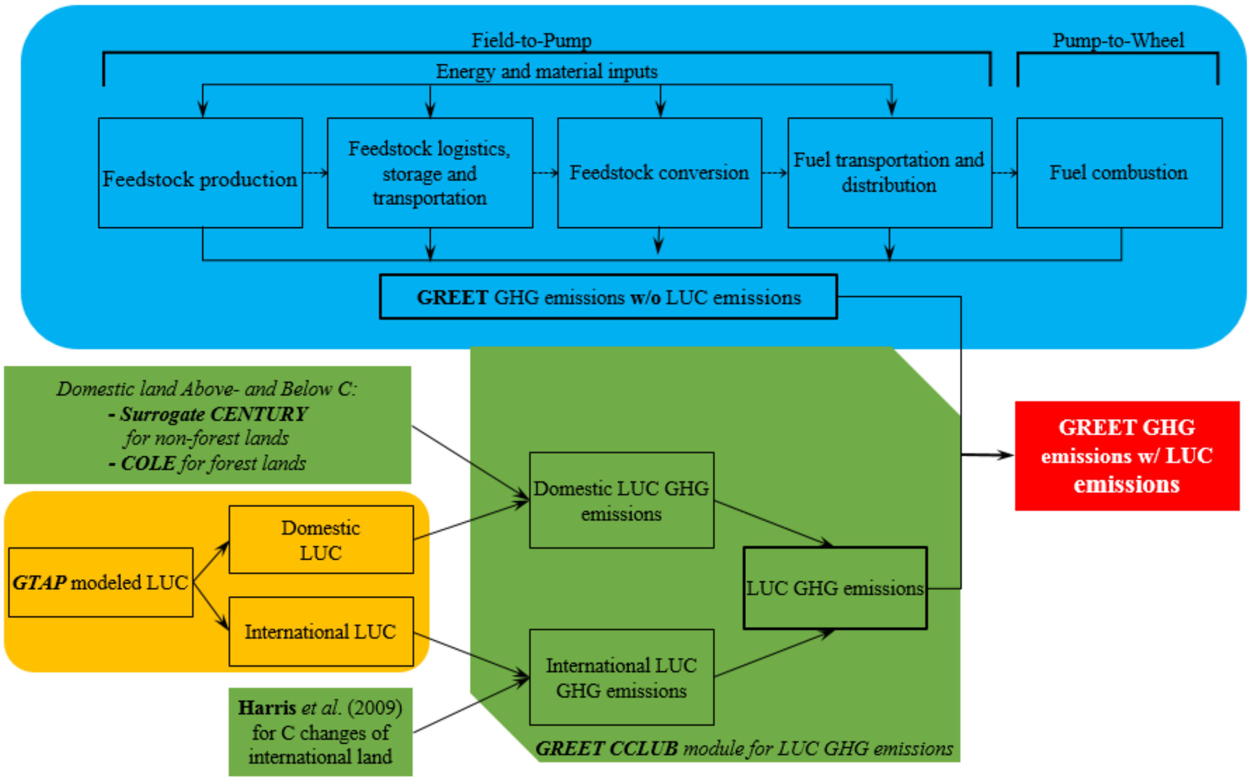
Interaction between CCLUB module and main GREET model



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SOC modeling and CCLUB development are based on collaborations/interactions with other teams

Colorado State U.

e.g., modified yield inputs, added model parameterizations/ calibration

Kwon et al. 2017

Use of inverse modeling to evaluate CENTURY-predictions for soil carbon sequestration in US rain-fed corn production systems

Hoyoung Kwon[1]*, Carmen M. Ugarte[2], Stephen M. Ogle[3], Stephen A. Williams[3], Michelle M. Wander[2]

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Surrogate CENTURY

Purdue U.

GTAP

Tyner et al. 2010

Land Use Changes and Consequent CO_2 Emissions due to US Corn Ethanol Production: A Comprehensive Analysis*

By

Wallace E. Tyner
Farzad Taheripour
Qianlai Zhuang
Dileep Birur
Uris Baldos

July 2010

Department of Agricultural Economics
Purdue University

Taheripour & Tyner, 2013

Appl. Sci. 2013, 3, 14-38; doi:10.3390/app3010014

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Article

Biofuels and Land Use Change: Applying Recent Evidence to Model Estimates

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Taheripour et al., 2017

Biotechnology for Biofuels

RESEARCH — Open Access

The impact of considering land intensification and updated data on biofuels land use change and emissions estimates

Farzad Taheripour, Xin Zhao and Wallace E. Tyner*

GREET LIFE CYCLE ANALYSIS

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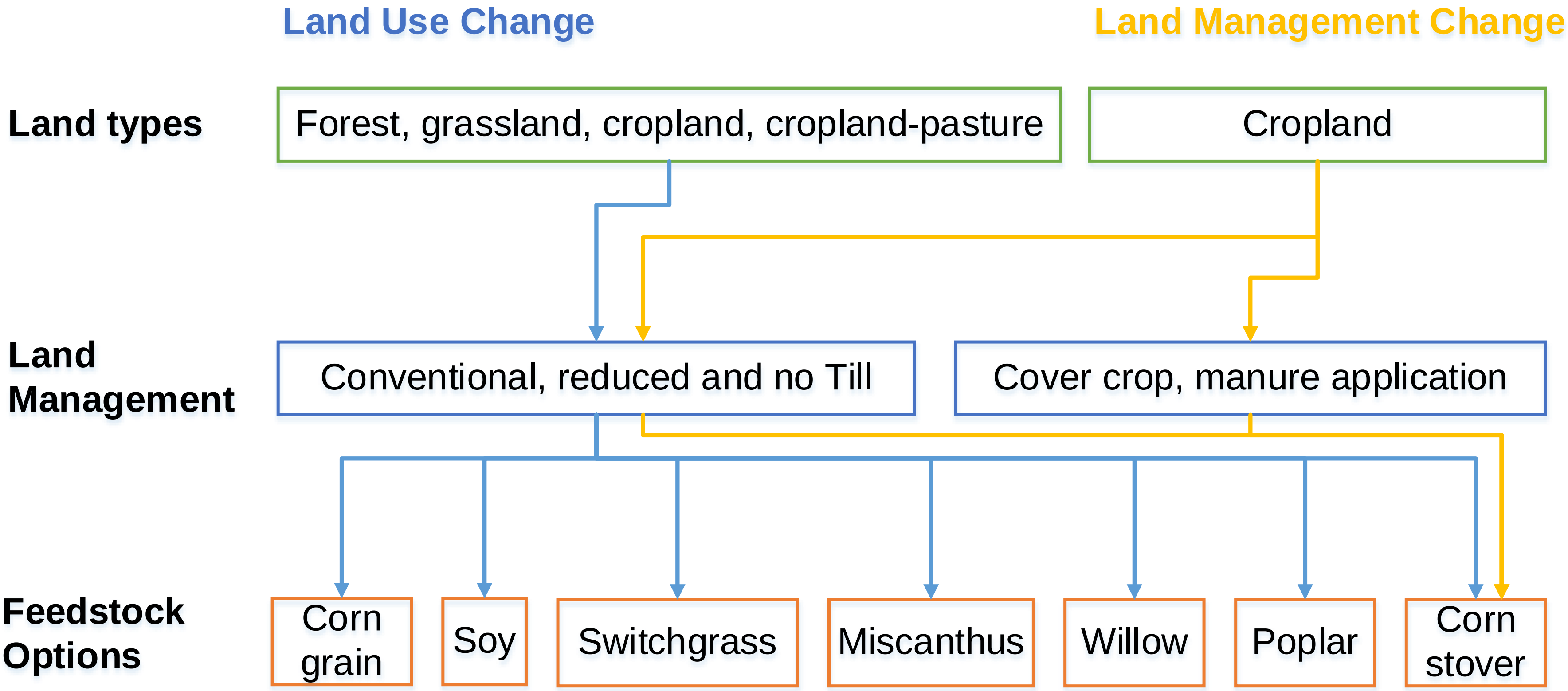
CCLUB contains *nine* cases for biofuels production

Case	GTAP modeling	BG/year
1) Corn Ethanol 2011	Increase in corn ethanol production from its 2004 level (3.41 billion gallons [BG]) to 15 BG	11.59
2) Stover Ethanol	Increase of ethanol from corn stover (i.e. AdvfE-Stover) by 9 BG, on top of 15 BG corn ethanol (continuous corn)	8.97
3) Miscanthus Ethanol	Increase of ethanol from miscanthus (i.e. AdvfE-Misc) by 7 BG, on top of 15 BG corn ethanol	7.03
4) Switchgrass Ethanol	Increase of of ethanol from switchgrass (i.e. AdvfE-Swit) by 7 BG, on top of 15 BG corn ethanol	7.03
5) Corn Ethanol 2013	Increase in corn ethanol production from its 2004 level (3.41 BG) to 15 BG, with GTAP calibrated land transformation parameters	11.59
6) Soy Biodiesel_CARB case 8	Increase in soy biodiesel production by 0.812 BG, using California Air Resources Board (CARB) case 8	0.812
7) Soy Biodiesel_CARB Average Proxy	Increase in soy biodiesel production by 0.812 BG, using California Air Resources Board (CARB) average of 30 cases	0.812
8) Soy Biodiesel_GTAP 2004	Increase in soy biodiesel production by 0.8 BG, using GTAP with land intensification, 2004 database	0.8
9) Soy Biodiesel_GTAP 2011	Increase in soy biodiesel production by 0.5 BG, using GTAP with land intensification, 2011 database	0.5

Production of bioenergy feedstocks can cause land-use change and/or land management change



Soil organic carbon modeling is a key tool in evaluating potential SOC changes under LUC/LMC

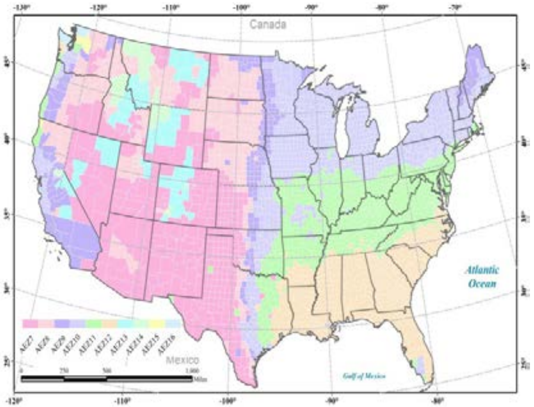
- Capture site- or region-specific soil and climate conditions
- Examine influence of agricultural practices
- Control variables that influence SOC systematically
- Incorporate different time horizons


Credit: J. B. Dunn

Soil carbon change upon land transitions/ land management depends on many factors

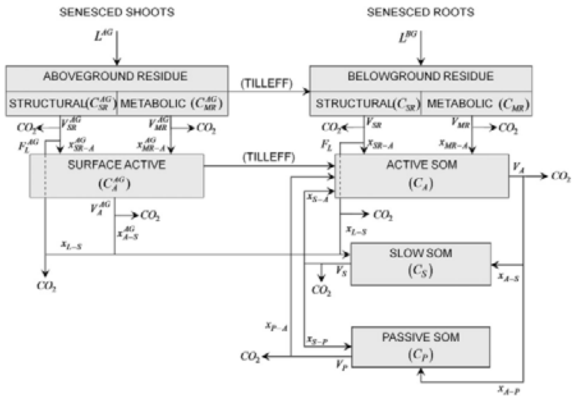
- Land use history (to SOC status)
- Yield
- Climate
- Soil depth for measurement and simulation
- Management practices

Soil carbon modeling with a surrogate CENTURY model



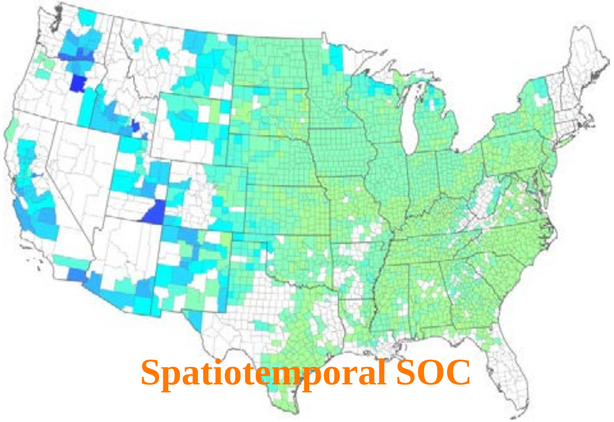
Spatiotemporal database

Including climate, soil, and yield information



Surrogate CENTURY model

By UIUC/IFPRI



Spatiotemporal SOC

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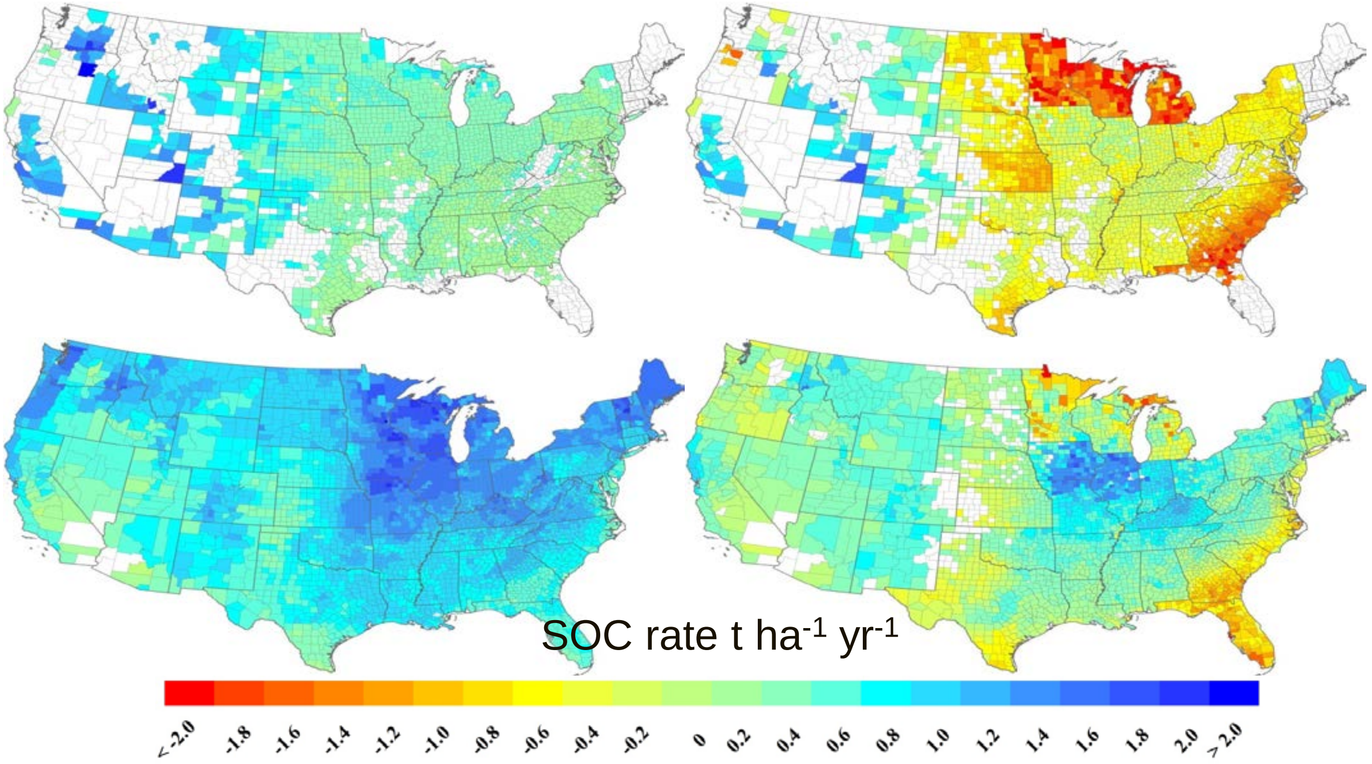
Soil organic carbon changes upon land transition vary spatially and by feedstock type

From Cropland Pasture | **From Forest**

To Corn

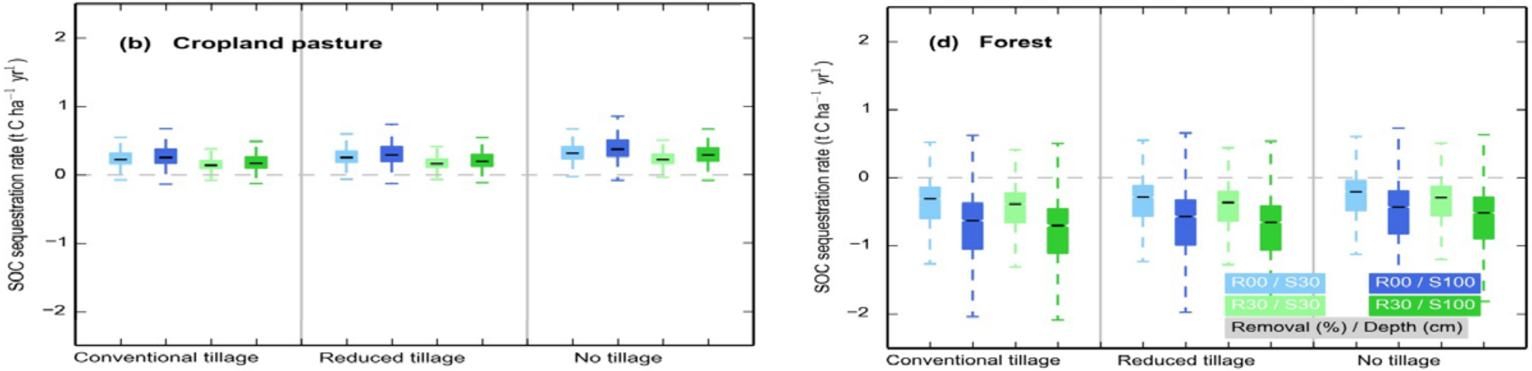
To *Miscanthus*



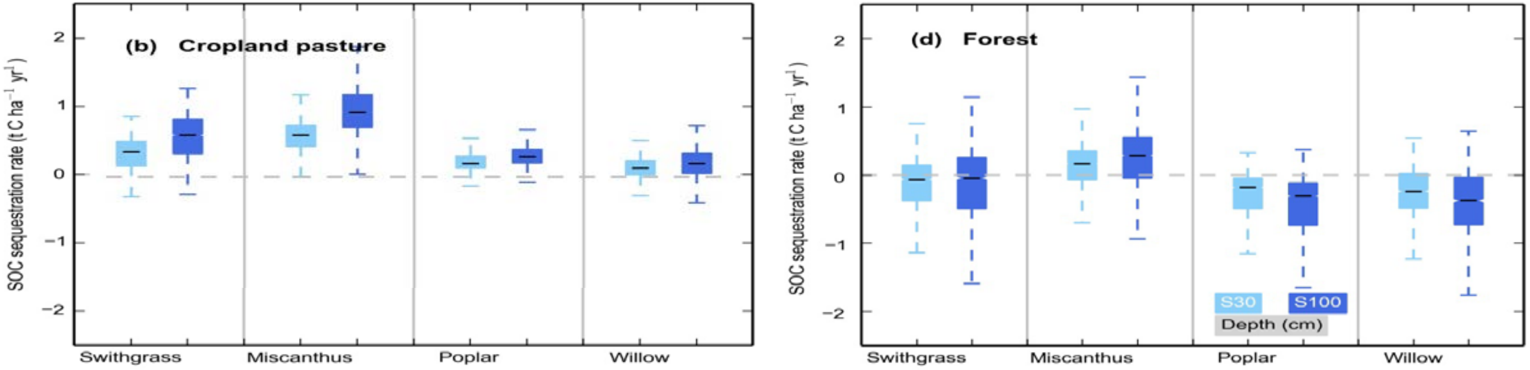
Qin *et al*., *GCB Bioenergy*, 2016

Nationwide SOC changes upon LUC and LMC have been rolled into CCLUB to estimate SOC impacts on GHG emissions

Corn/ Corn residues

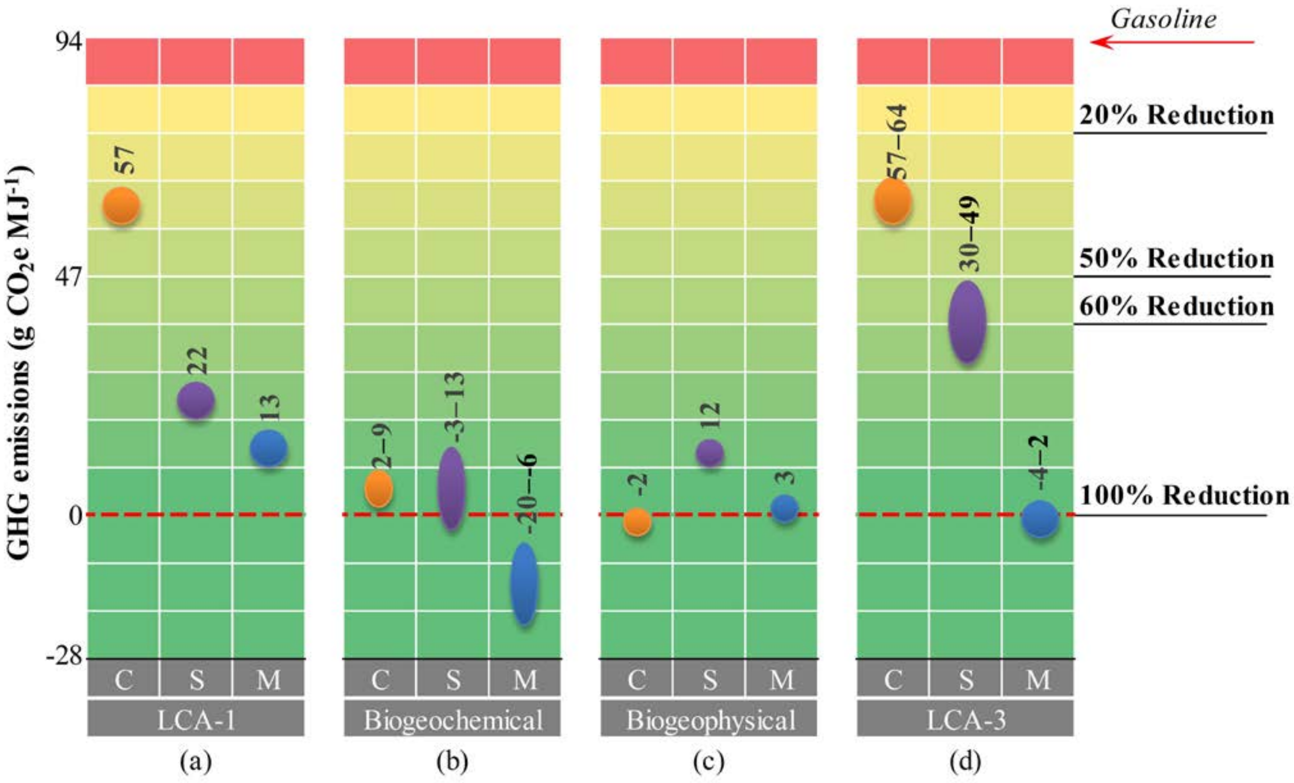


Cellulosic/ Woody Feedstocks



Qin *et al.*, *GCB Bioenergy*, 2016

LUC and resulted SOC change influence biofuel's life-cycle GHG emissions



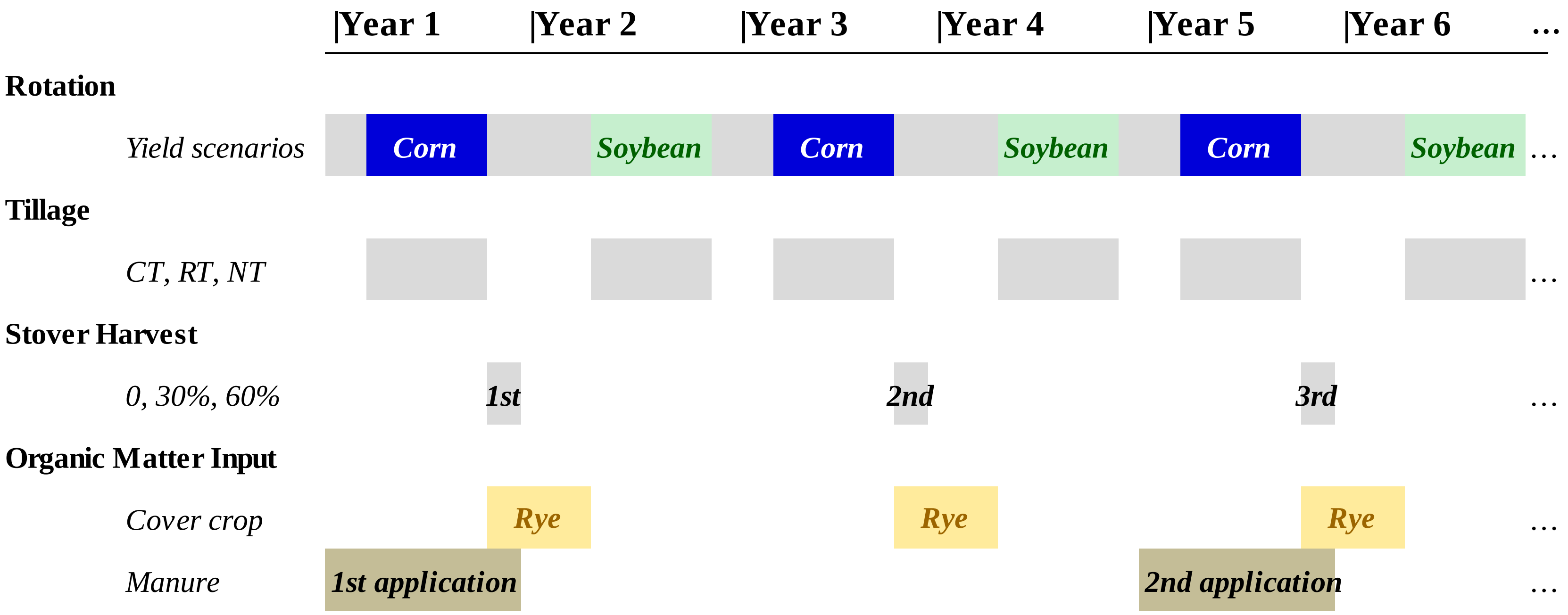
(a) LCA w/o LUC
(d) LCA w/ LUC
(b)biogeochemical (SOC) and (c) biogeophysical (albedo) impacts

C: Corn
S: Switchgrass
M: Miscanthus

*<u>*The range reflects variable LUC/SOC scenarios.</u>*

Qin *et al., AGU Book*, 2017

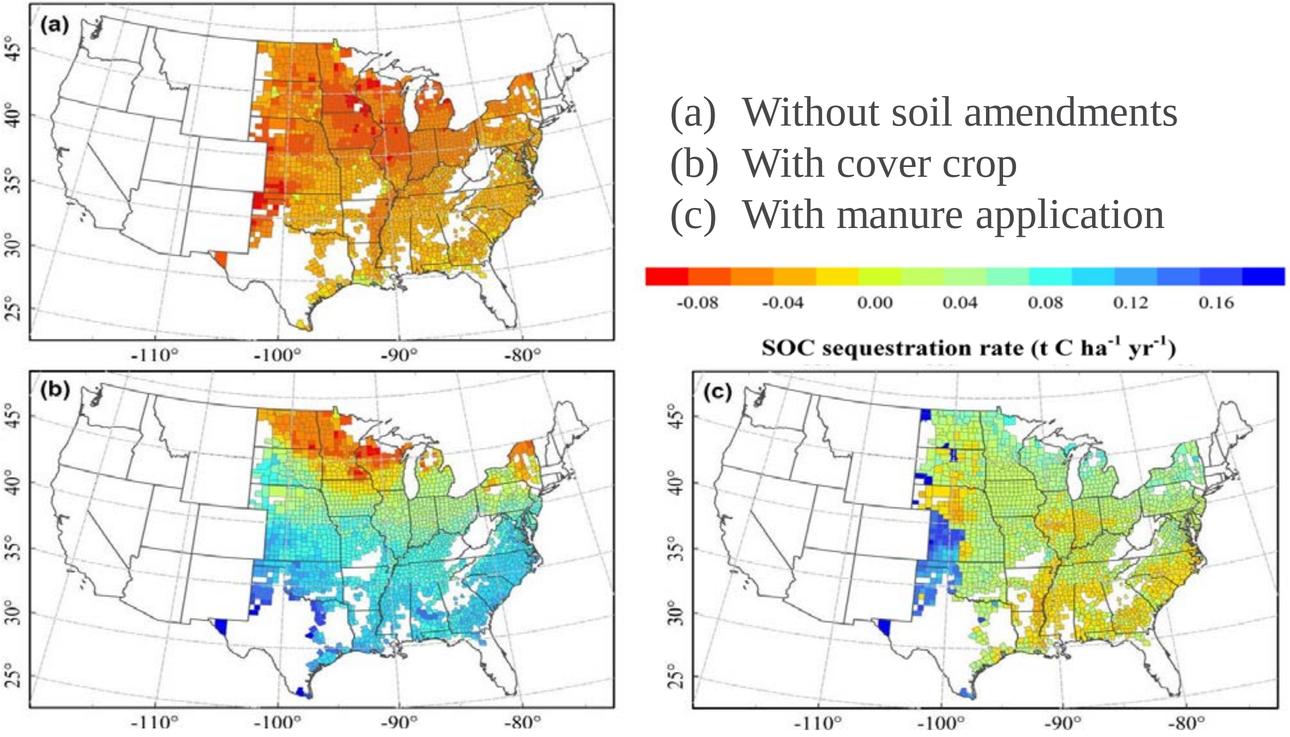
A recent Argonne study on corn/corn stover ethanol looked into specific management practices: stover removal, tillage, cover crop, manure



Qin *et al.*, ANL/ESD-15/26, 2015

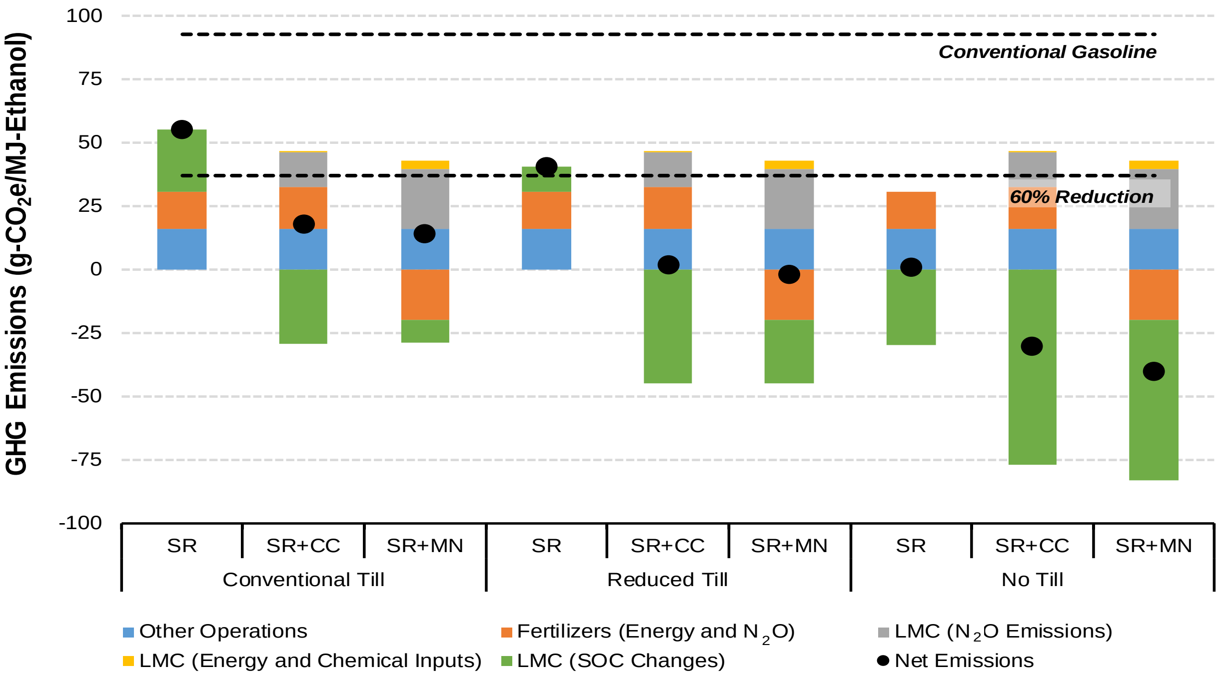
SOC level reduces with corn stover removal, but may maintain or even improve with additional soil amendments applied

(a) Without soil amendments
(b) With cover crop
(c) With manure application



SOC change for 30% stover removal, relative to zero removal.

SOC change upon land management may dramatically affect corn stover ethanol life-cycle GHG emissions



SOC impacts

SR: stover removal
MN: manure
CC: cover crop

SOC change simulation, esp. for LMC, is still uncertain and limited in many ways

- LMCs in practice vs. in simulation
- Multiple LMCs occur at the same time/field: integrated vs. additive effects
- Land management counterfactual scenarios: what biofuel production causes?
- Enough evidence to support process-based LMC-SOC relationship?
- A SOC database w/ nationwide experimental observation data (especially long-term) can be helpful to validate process-based models
- N_2O emission simulations are based on mass balance of N input and removal; need N cycle dynamics and N inputs/removal ratios for soil

Summary

- ❑ **Biomass feedstocks production can result in land use change and land management change**
- ❑ **Land use & management change both have significant SOC effects which eventually impact on biofuel's life-cycle GHG emissions**
- ❑ **Field observation network/database to assist SOC modeling (esp. with management practices) are important to validate and improve SOC modeling for biofuel LCA**

Acknowledgements

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