DOE Bioenergy Technologies Office (BETO) 2023 Project Peer Review

Benefits and LUC Effects of US Energy Crop-based Carbon Banking

Technology Area Panel: Feedstock Technologies

Principal Investigator: Gbadebo Oladosu

Organization: Oak Ridge National Laboratory

April 3, 2023

Evaluate the potential and benefits of energy crop carbon banking as a carbon dioxide removal (CDR) strategy

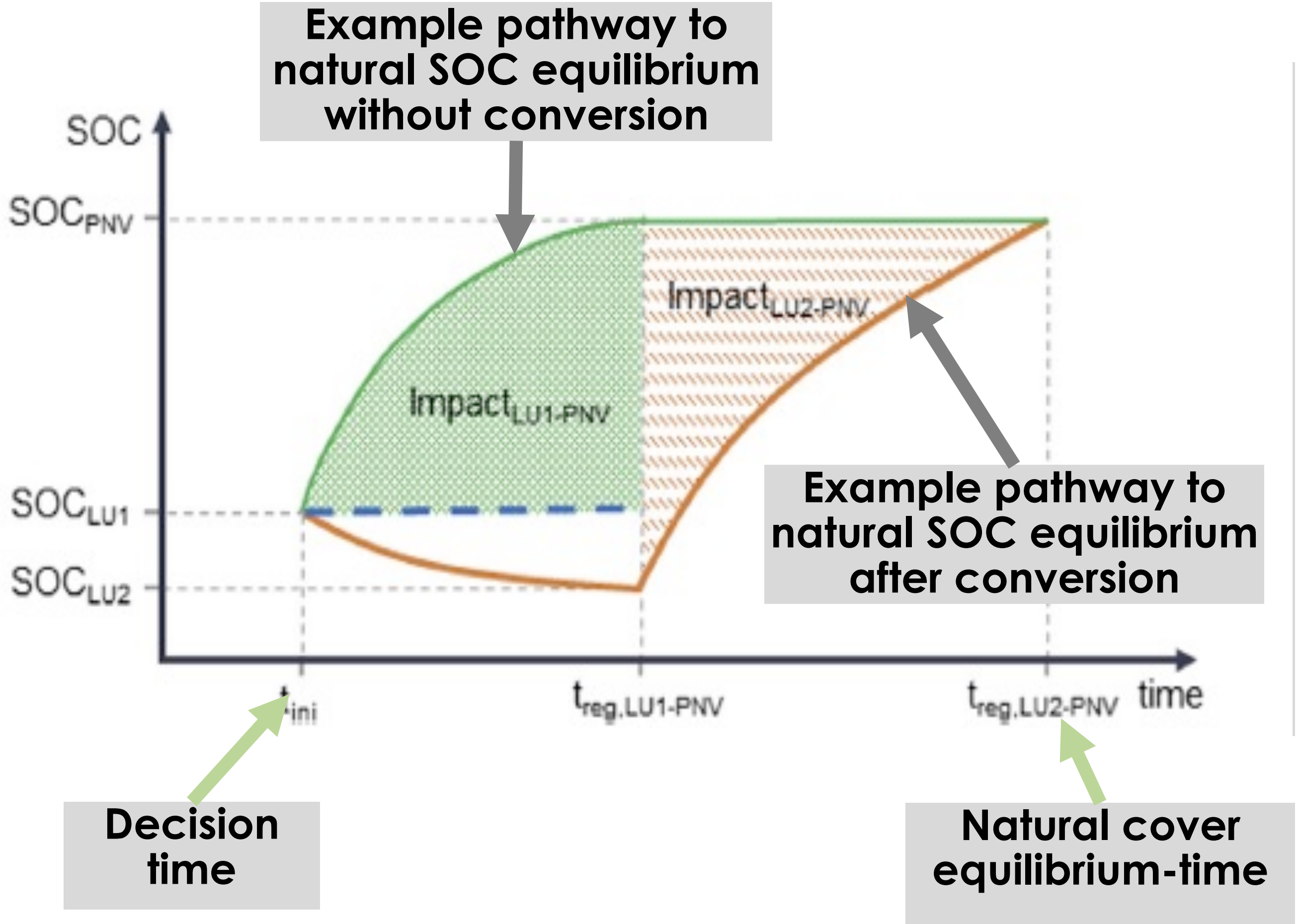
- **Motivation:**
  - Energy crops can potentially be produced on 22 to 88 million acres* of US land:
    - …and could sequester significant amounts of soil organic carbon (SOC)
  - Carbon banking can accelerate US energy crop production by:
    - …providing a SOC value stream to farmers and other stakeholders
  - "No…studies mapping the potential …of specific cropland CDR strategies exist"**

- **Project goals:**
  - Develop critical information for decision-making related to US energy crop carbon banking
    - Identify scenarios to optimize the benefits/sustainability
  - Assess conditions for accelerating energy crop carbon banking

*2016 BILLION-TON REPORT https://www.energy.gov/sites/prod/files/2016/12/f34/2016_billion_ton_report_12.2.16_0.pdf
**Section 3.2.2 in CDR Primer: https://cdrprimer.org/read/chapter-3

Details of land use for energy crops production are essential for carbon banking

- **Soil Organic Carbon (SOC) is key to energy crop carbon banking but:**
  - …difficult to measure
  - …spatially heterogeneous
  - …dynamic and path-dependent
  - …depends on both **above- and below-ground (ABG & BG)** biomass uses



Source: Morais et al., 2018

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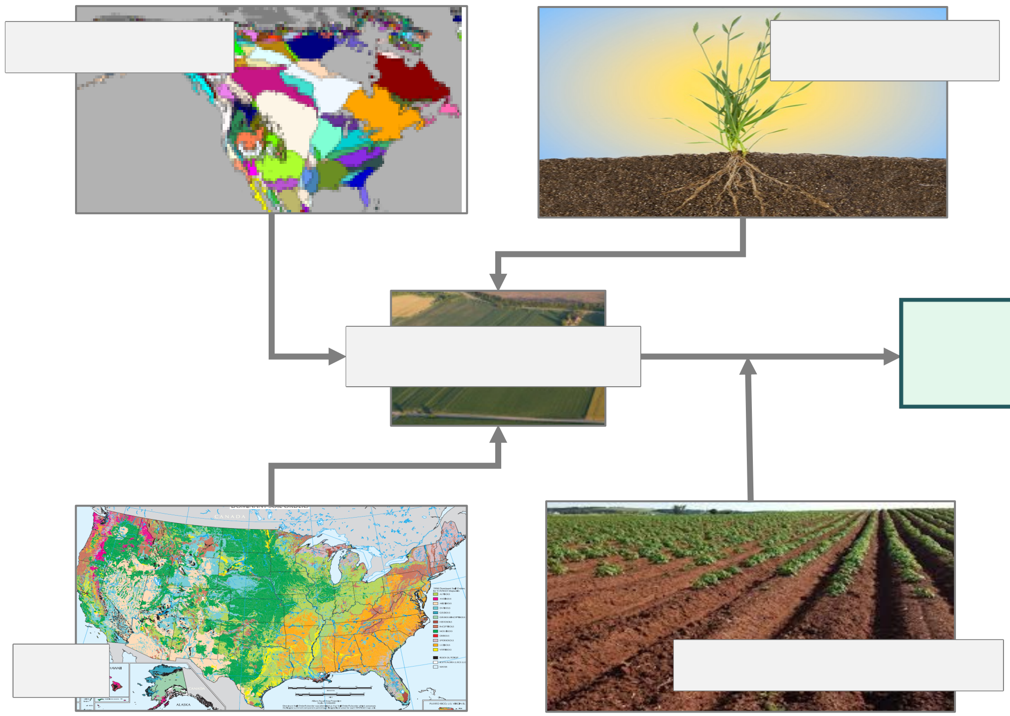
Bottom-up framework for energy crop carbon banking potential and benefits assessment

- **Carbon Banking Potential Assessment: RothC; AI/ML Models**



- **Benefits and LUC Impacts Assessment: ABM*; POLYSYS; GCAM Models**

Major Gap

National & Global Land Use Change Impacts

Economic and Other Sustainability Indicators

Carbon Banking Potential & Feasibility Database

- **Planned Outcome:** Spatially explicit estimates of energy-crop carbon banking potential, and regional to global estimates of benefits and land use change impacts.

*ABM = Agent-based Model
AI/ML = Artificial Intelligence/Machine Learning

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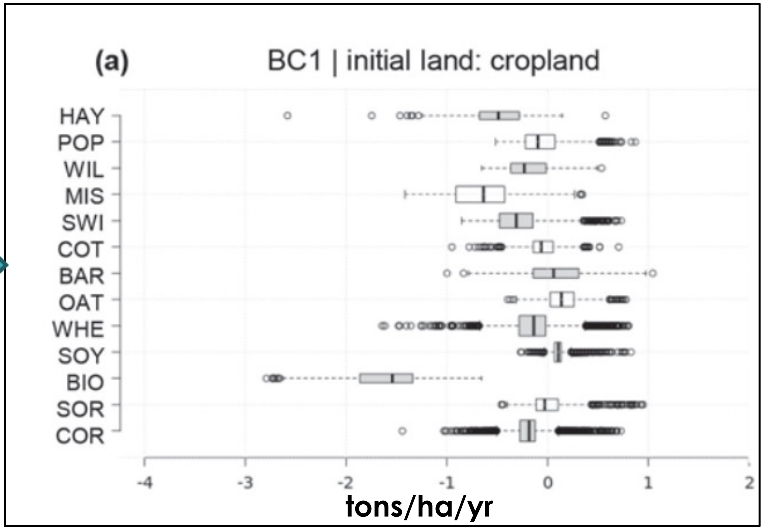
Project tasks are aimed at enabling US energy crop carbon banking and its sustainability

- **Task1: Develop an AI/ML-Aided* Rapid Approach for Detailed Evaluation of the Technical Potential for Energy Crop Carbon Banking from Parcel to National Scale**
- **Task 2: Evaluate the Benefits of US Energy Crop Carbon Banking Scenarios and Effects on National/Global Agricultural Markets and LUC**
  - Collaborate with PNNL/NREL on the potential use of GCAM for global analyses
- **Task 3: Evaluate the Sustainability Effects of US Energy Crop Carbon Banking, including Equity**

*AI/ML = Artificial Intelligence/Machine Learning

Challenges, risks and mitigation strategies

- **Challenges and Risks:**
  - Data to understand the current stock of SOC are scarce/dated
  - Range of modeled energy crop SOC sequestration is wide
    - Driven by systematic variations in SOC determinants
  - No standard model for SOC assessment



- **Risk Mitigation**
  - Evaluated existing approaches for regional/global SOC assessment
    - There is a major gap in translating small-scale studies of SOC for use in large-scale assessment
  - Devoted time to compiling available detailed data at the national scale
  - Selected an accessible but well-recognized model for SOC estimation

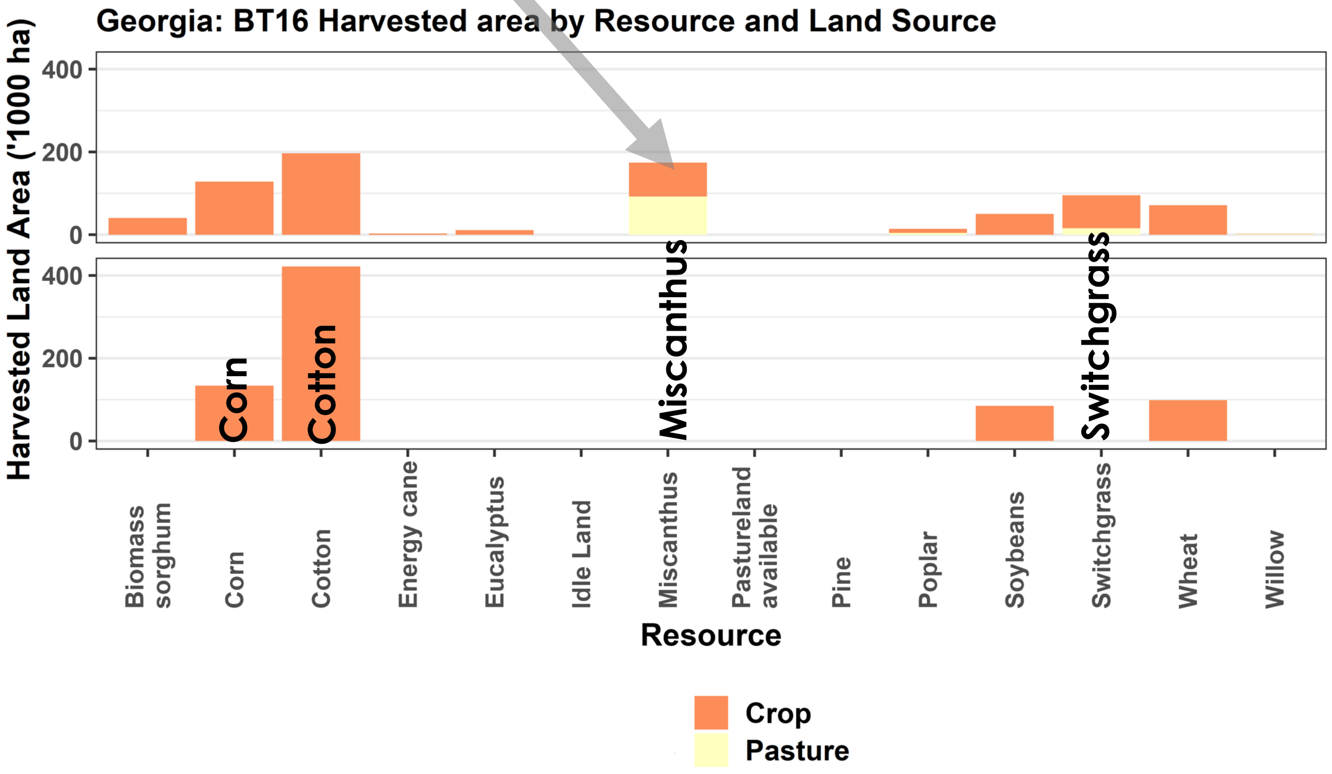
Go/No-Go Criterion: Are there significant US/Global LUC and other effects of energy crop carbon banking? Likely

- **Example: BT16 estimates of land use for energy crops in Georgia**
  - ~300K ha of Miscanthus & Switchgrass in 2040 (**land from pasture, cotton & other crops**)

- What are the SOC implications of year-to-year land-use changes relative to the baseline?

- Does using crop residues for energy production compensate for changes in soil carbon?

- What combinations of energy crops are optimal for CDR?



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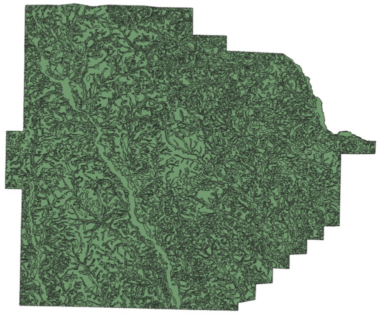
Compiled detailed data for SOC sequestration assessment

- **Land use and crop characteristics data:**
  - 2020 USDA Crop Data Layer (CDL)
  - Crop constraints & ABG/BG biomass for about 620 species*
- **USDA SSURGO national soil database**
  - Base SOC estimates and other variables: Texture, Clay, etc.
- **Monthly averages of climate variables for 1991-2020:**
  - Temperature, precipitation, etc. from TerraClimate database**
- **Program developed to compile county-level datasets**
  - Indexed by **MUKEY** (SSURGO Soil Mapunits) & **LUID** (CDL land use ID)
- **Identified potential sources for updating national SOC stock data**
  - ORNL DAAC – SOC & Carbon pool estimates
  - NRCS Rapid Carbon Assessment Project (RACA)
- **Exploring the use of High-Performance Computing (HPC) Capabilities**

Example: Soil Mapunits for Tift County, GA

- **>1,200 MUKEY-LUID**

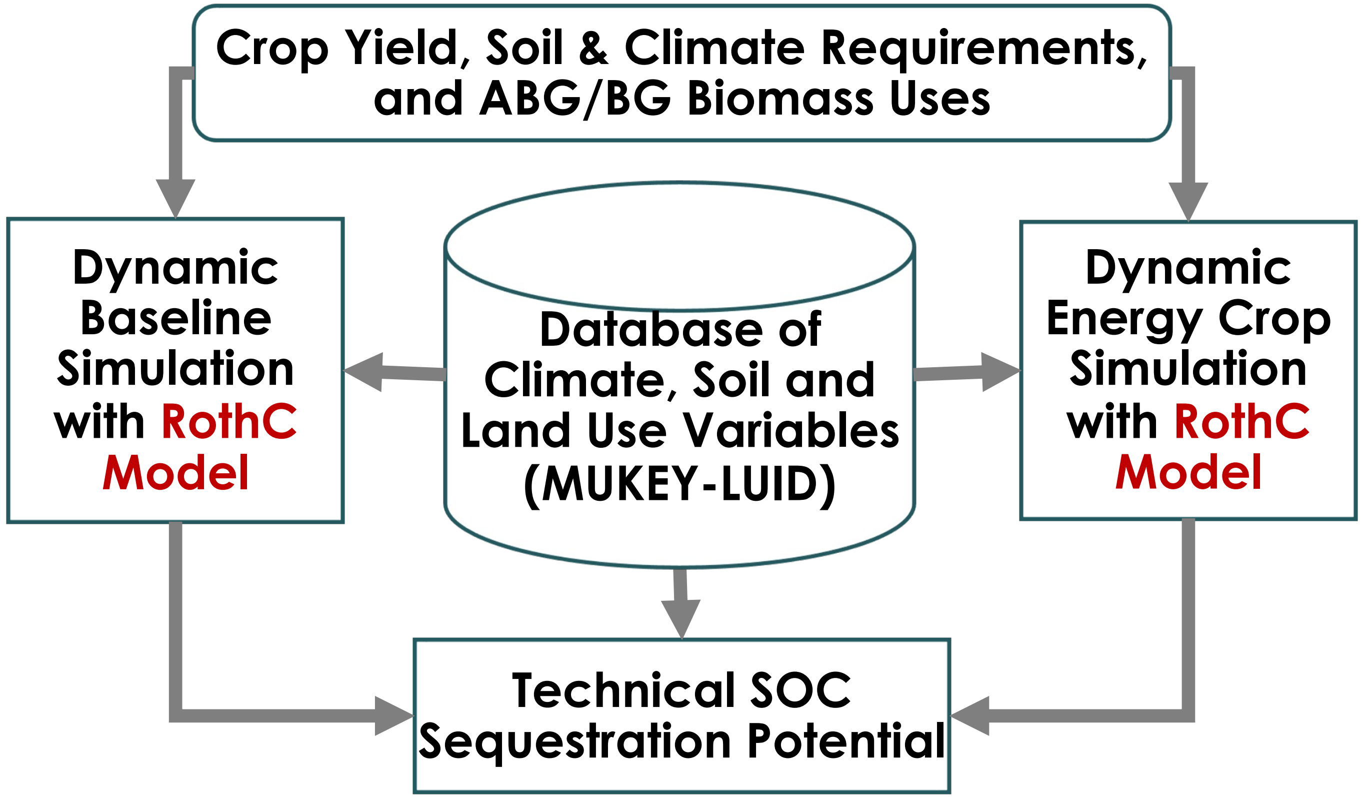


*Albers, et al. (2022) Supplementary data
**https://www.climatologylab.org/terraclimate.html

Preliminary simulations to evaluate switchgrass SOC sequestration potential

- Focusing on existing cropland, grassland, and shrubland
- 100-yr time horizon in monthly time-steps

- **RothC** is an established model for modeling soil organic carbon (SOC) turnover in response to environmental conditions and management.**



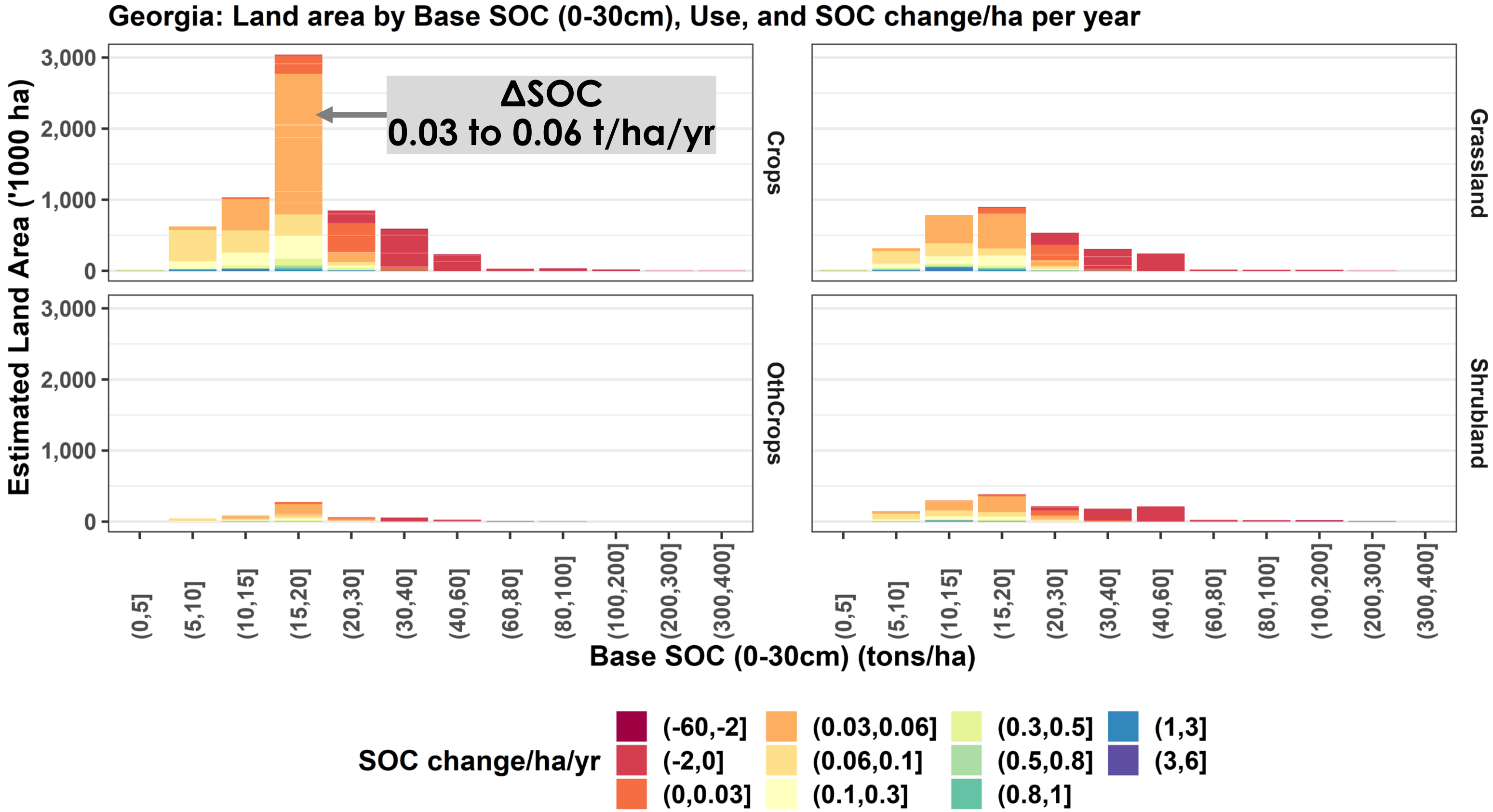
**Coleman & Jenkinson, 2014

Switchgrass simulations found SOC (0-30cm layer) accumulation in soils with low initial stock levels

- **SOC Stocks < 20 tons/ha:** SOC sequestration range of 0.03 to 3 tons/ha/yr
  - – Wide range of estimates emphasizes the importance of detailed SOC assessments

- **Carbon inputs to the soil**:
  - Yield of ~12 dt/ha
  - Harvest index of 90%
  - 0.34 t/ha/yr ABG biomass
  - 4.45t/ha/yr of BG biomass
  - 50% annual root turnover

- **Notes:**
  - Land transitions are for comparison purposes only

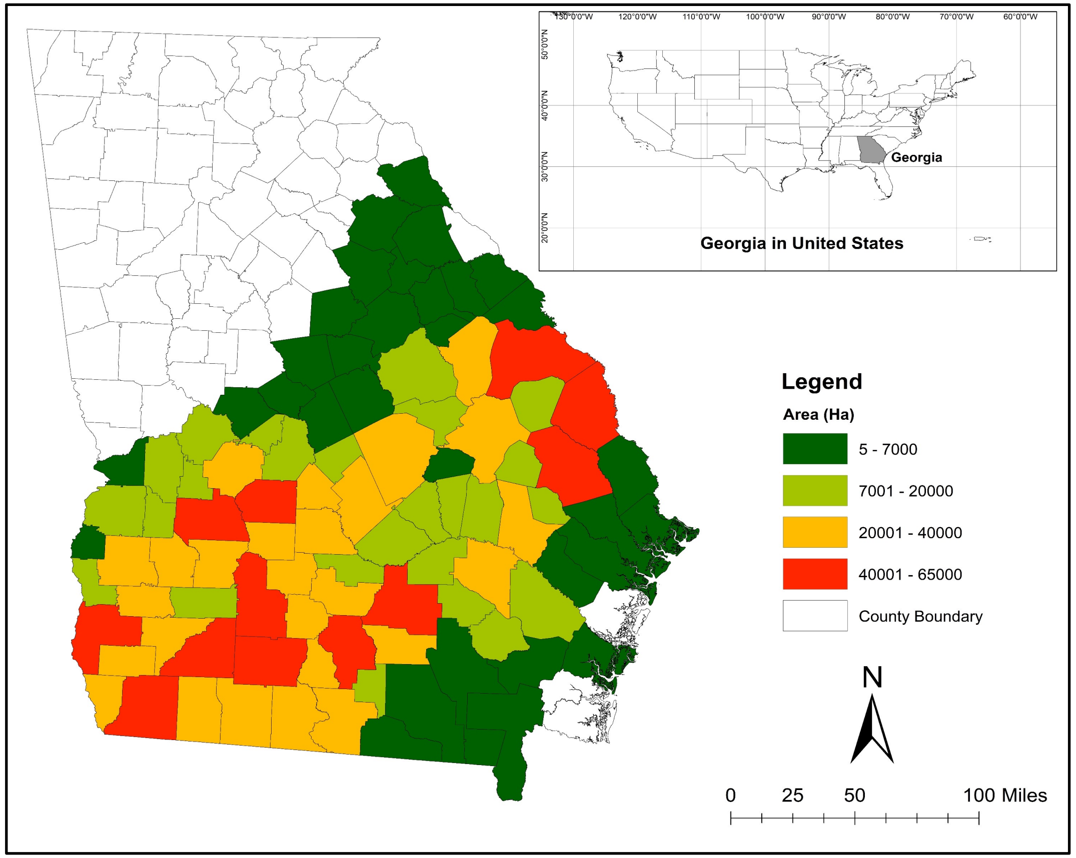


Assessing the benefits of SOC incentives for Carinata

- **Carinata is a potential key feedstock for Sustainable Aviation Fuel (SAF)**

- **ABM incorporates sub-models of:**
  - Profit maximization
  - Adoption diffusion (neighbor influence)
  - Land allocation to carinata*
    - Agents = farmers with farm sizes based on Ag. Census distribution

- **Builds on previous work:**
  - Evaluates the impacts of SOC incentives
    - Proxy for carbon banking price



Potential land available for carinata production**

*Model based on Embaye, et al., 2018;
**Field et al. 2022

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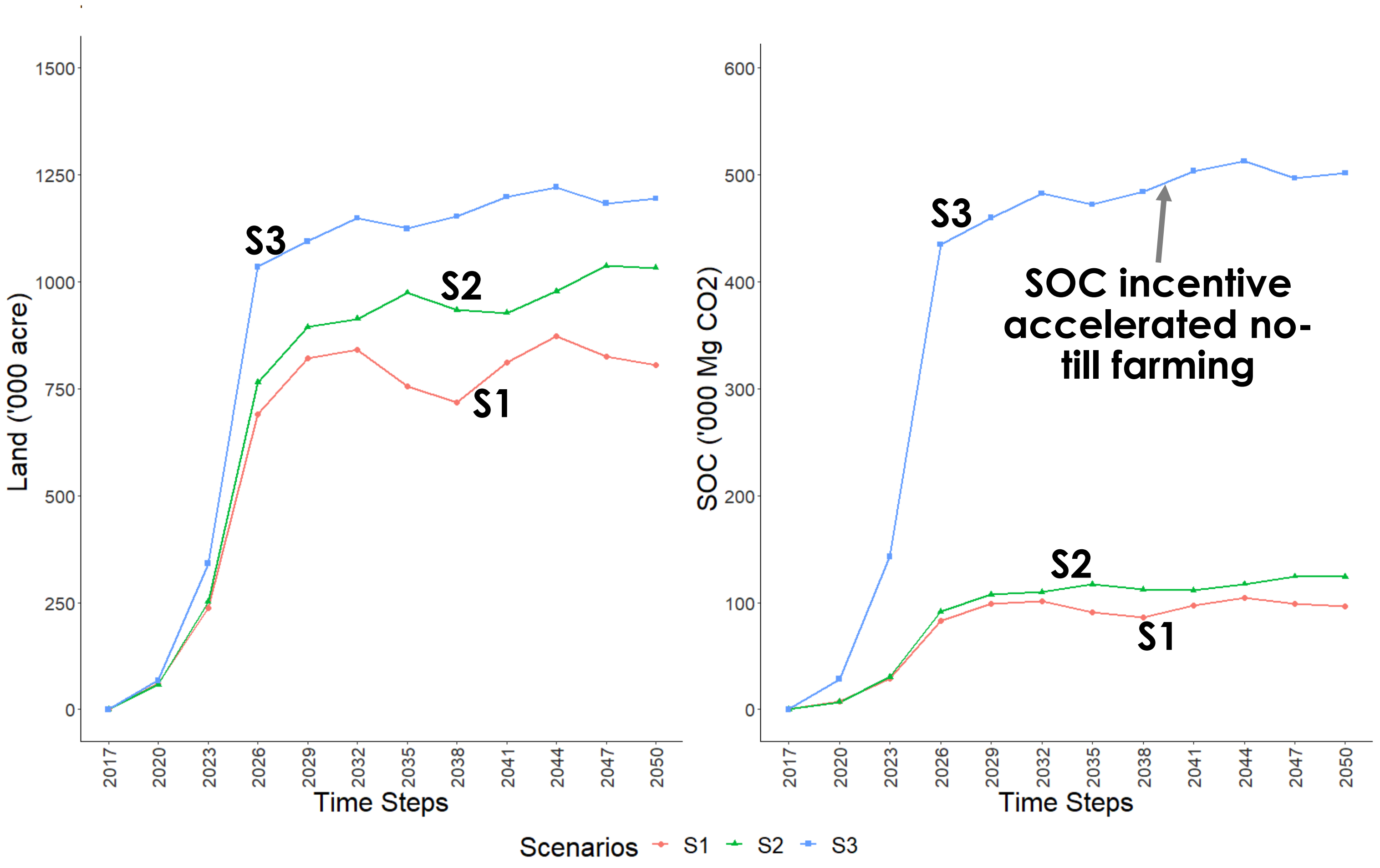
SOC incentive leads to a significant increase in carbon sequestration with carinata production

Carinata Simulation Scenarios

	Farming Type	Seed Price	SOC Incentive
S1	Conventional	$5.5/bu	$150/MgCO2e
S2	Conventional	$6/bu	$0
S3	No Till	$5.5/bu	$150/ MgCO2e

- Without SOC incentives, farmers focus on carinata yield to maximize profits
  - …but maximum yields do not necessarily produce optimal SOC sequestration



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Project outcomes will help accelerate US energy crop carbon banking and its sustainability

- Energy crop production can sequester SOC, but this is not well-understood
  - Project assesses the SOC potential of energy crops and the role of carbon banking
- Project outputs will provide support for R&D and private industry:
  - Estimates of SOC sequestration potential will serve as a crucial starting point for stakeholder assessments of energy crops for carbon banking
  - Compiled data and programs for SOC estimation will be publicly available
- Sustainability impacts assessment will help to:
  - …resolve potential national/global land use change issues for energy crop production
  - …understand the role of SOC banking in promoting equity in farming communities
- Project provides post-doc training opportunities to support manpower development for R&D in natural resource management

Carbon sequestration with energy crops could be significant but implementation requires careful assessment

- Initial results:
  - Significant potential for SOC sequestration with energy crops
  - Valorization of SOC necessary to achieve energy crop carbon sequestration potential
- SOC is spatially heterogeneous and dynamic
  - Detailed assessments are indispensable for a successful SOC banking program
- Co-optimization of energy crop biomass uses for low-carbon energy production and SOC accumulation would be necessary for an overall CDR strategy
- Ongoing/Future work:
  - Refine estimates of US potential for energy crop SOC and apply to other SE states & crops
  - Translate estimates of SOC banking potential into forms that preserve essential details, and use these for regional/global analyses of the benefits, LUC effects, and sustainability
  - Further development of the ABM model for application to other SE states & energy crops
  - Evaluate conditions for accelerating US energy crop carbon banking and sustainability

Quad Chart Overview

Timeline

- ***Project start date***: *10/1/2021*
- ***Project end date***: *9/30/2024*

	FY22 Costed	Total Award
DOE Funding	*$466K*	*$1,398K*
Project Cost Share *	N/A	N/A

TRL at Project Start: N/A
TRL at Project End: N/A

Project Goals

The goal of this project is to develop critical information for decision-making related to carbon banking using energy crops in the US. Detailed analyses will support a set of recommendations for the deployment of energy crops in a manner that (a) optimizes benefits (social, economic, environmental) adapted to site-specific conditions and (b) creates incentives for beneficial LUC effects at a global scale. The project will also assess the sustainability, including equity, implications of energy crop-based carbon banking on affected U.S. communities.

End of Project Milestones

- *Public-facing database of US carbon banking potential for 1-3 energy crops;*
- *An accessible method for multi-objective evaluation of economic, social and environmental sustainability indicators for plausible energy carbon banking scenarios;*
- *Reports and papers documenting US energy crop carbon banking potential, national/global benefits, and the land use change implications of the given set of scenarios*

Funding Mechanism

Feedstock Technologies FY22 Lab Call

- *AOI topic: 2a-3: Global Land Use Change Impacts of Enhanced Carbon Banking*

Project Partners*

- ORNL: *Gbadebo Oladosu, Dan Jacobson, Keith Kline, Matt Langholtz, Esther Parish, John Lagergren. Kazi Ullah (postdoc);* PNNL: *Marshall Wise;* NREL: *Patrick Lamers*

Publications and Presentations

- Ullah, K.M. & Crooks, A (2022) Modeling Farmers' Adoption Potential to New Bioenergy Crops: An Agent-based Approach, Proceedings of the 2022 Conference of the Computational Social Science Society of the Americas - Computational Social Science 2022, Springer Nature.
- Ullah, K.M., Masum, F.H., Field, J., & Dwivedi, P. (2023) Designing a GIS-Based Supply Chain for Producing Carinata-Based Sustainable Aviation Fuel in Georgia, Biofpr, Willey (accepted)
- Ullah, K.M., Crooks, A., & Oladosu, G.A (2023) Evaluating the Incentive for Soil Organic Carbon Sequestration from Carinata Production in the Southeast US (under preparation)
- Ullah, K.M., Field, J & Oladosu, G.A. (2022) US and Global Soil Carbon Sequestrations from Climate-Smart Agricultural Practices: An Overview of Existing Studies (draft white paper)
- Ullah, K.M. & Dwivedi, P. Designing Carinata-Based Sustainable Aviation Fuel Supply Chain in Georgia Under Uncertainty (under preparation)

Appendix

Abstract

- Carbon banking can help accelerate the production of energy crops in the US by valuing the associated increases in soil organic carbon (SOC). Although SOC sequestration has received significant attention, details of national land transitions, potential land use change (LUC), and other effects are not yet well-understood but essential to energy crop carbon banking. These LUC and other “off-farm” impacts have already been identified as potentially limiting the role of carbon sequestration in agricultural soils for reducing GHG. Therefore, as with using food crops to produce biofuels, LUC, and other effects must be addressed when transitioning US soils to energy crop carbon banks. In addition, SOC is highly dynamic and spatially heterogeneous, requiring detailed assessments to reduce uncertainties and carbon banking risks. This project supports DOE, BETO, and private industry by providing national/global level information and analyses to address these issues to enable energy crop carbon banking in the US. The project will examine scenarios for SOC sequestration, the national benefits, and the LUC effects of global interactions in the economy's agricultural, energy, and other sectors. The project will seek to identify opportunities to maximize the complementary benefits of land use for agricultural production and energy crop carbon banking in the US, as measured through environmental, social, economic, and equity sustainability indicators.

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- Embaye, W. T., Bergtold, J. S., Archer, D., Flora, C., Andrango, G. C., Odening, M., & Buysse, J. (2018). Examining farmers' willingness to grow and allocate land for oilseed crops for biofuel production. Energy Economics, 71, 311-320.

Planned 2023 Milestones

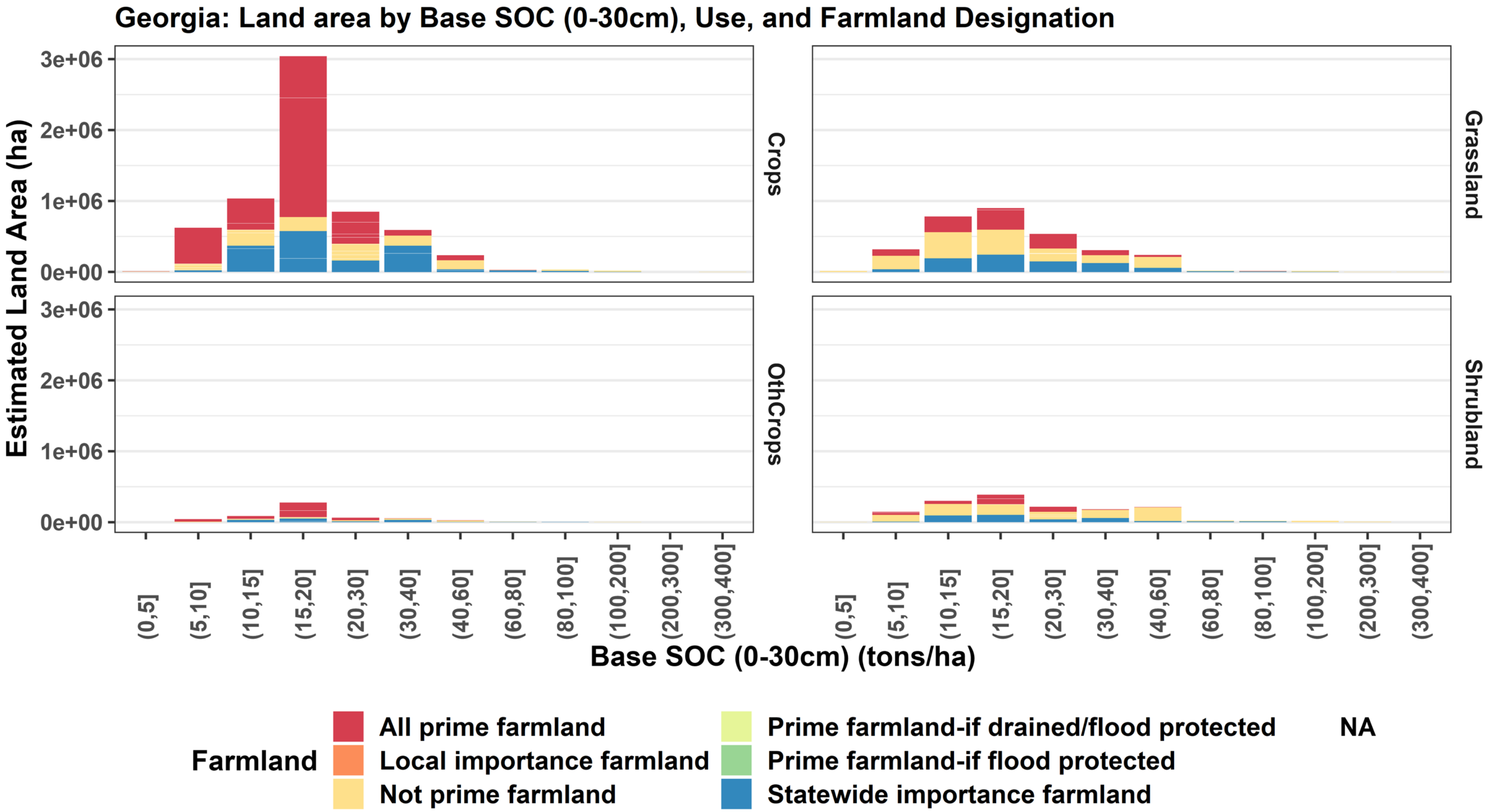
Milestone	Due date	Percent complete	Date Completed	On track?
Provide progress updates to BETO on: 1) Updating the baseline SOC data in the compiled database for simulations with the RothC model; 2) Performing simulations with the RothC model for 1 to 3 of the Northeast, Southeast, Corn Belt and Appalachian US regions; 3) Effort to engage public and private stakeholders support for data and other insights on energy-crop based carbon banking in the US	12/31/2022 FY23Q1	30%		Y
Complete white paper on potential of energy crop-based SOC sequestration; Draft paper on the cost/benefits effects of SOC banking on farmer adoption of energy crops	3/31/2023 FY23Q2	25%		Y
Crop-specific above- and below-ground C changes by county for the 1 to 3 of the Northeast, Southeast, Corn Belt and Appalachian regions for 2-3 energy crops. Results would include data on prior land use and associated price premium ($/ton of biomass) associated with C banking effect (tons C/acre), estimates of changes in land use requirements, agricultural production and trade associated with different scenarios of energy crop carbon banking in the region.	6/30/2023 FY23Q3	5%		Y
Provide updates to BETO on progress: 1) Preparing the necessary input data and changes to use GCAM for simulations of the potential global land use change impacts of US energy crop-based carbon banking; 2) Estimating the sustainability implications of energy crop - based carbon banking scenarios in one of the US farm regions.	9/30/2023 FY23Q4	5%		Y

Glossary

- ABG = Above-ground biomass
- ABM = Agent-based Model
- AI/ML = Artificial Intelligence/Machine learning
- BG = Below-ground biomass
- Carbon bank = A market framework for carbon credits transactions at prices determined by the balance of suppliers and buyers/borrowers
- CDL = Crop Data Layer (USDA)
- CDR = Carbon dioxide reduction
- GCAM = Global Change Analysis Model (Global energy, agriculture and macroeconomic model)
- Harvest index = Percentage of plant biomass harvested
- LUID = CDL Land use IDs
- MUKEY = SSURGO Map Unit Keys
- RothC = Rothamsted carbon model
- POLYSYS = Policy Analysis System Model (US agricultural sector model)
- SSURGO = Soil Survey Geographic Database (USGS)
- Root turnover = Percentage of plant roots replaced each year (and contributing to SOC)
- USDA = United States Department of Agriculture

Compiled Data Show a Wide Range of Base SOC (0-30cm) Stock: Georgia Example

- Large share in 0-20 t/ha SOC stock range imply potential to store carbon
- Low SOC stock levels point to sequestration potential



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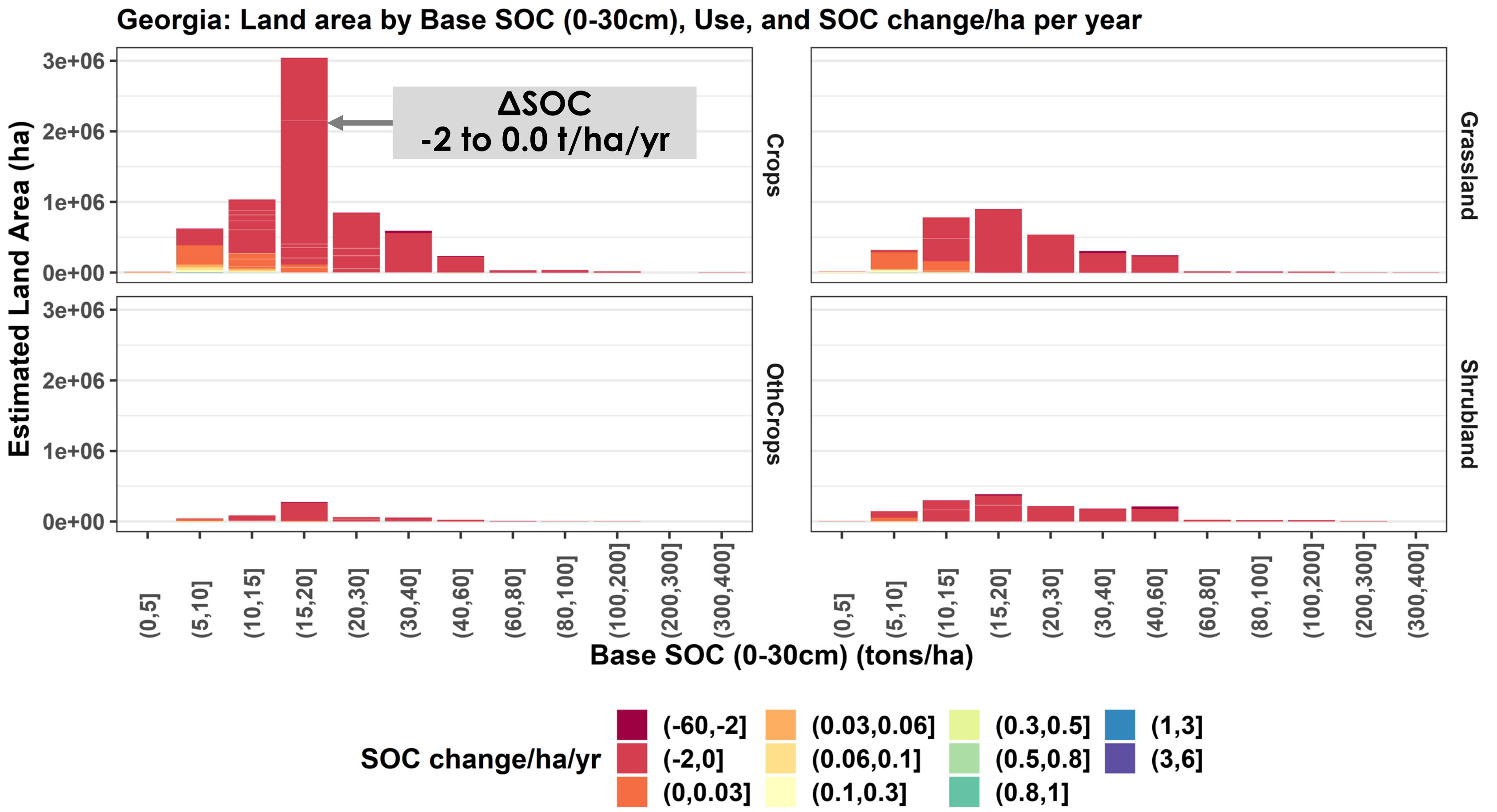
Baseline simulations for SOC (0-30cm layer) suggest current land uses could lead to SOC depletion over time

- Representatives used for existing land cover/use (e.g. corn for all cereals)
  - Calculated over 100 years (or SOC equilibrium year if less than 100 years)



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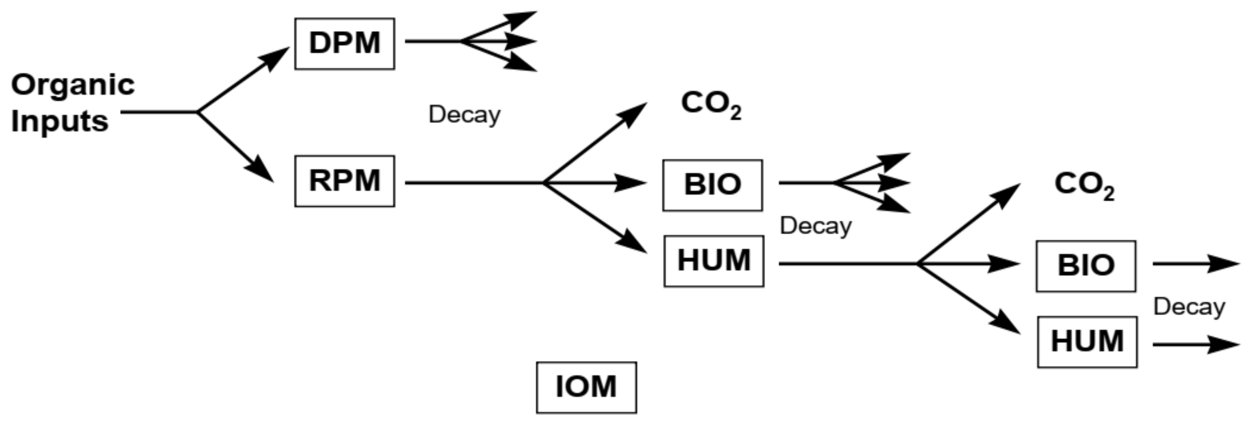
RothC’s Five SOC Compartments/Pools

- **4 active compartments** (RPM, DPM, BIO, HUM)
- **1 inert organic matter** (IOM) – resistant to decomposition
- Decomposition process based on first-order differential equations with different pool rates

Figure 1 - Structure of the Rothamsted Carbon Model



RPM : Resistant Plant Material
DPM : Decomposable Plant Material
BIO : Microbial Biomass
HUM : Humified OM
IOM : Inert Organic Matter

Coleman & Jenkinson, 2014

- Incoming plant material is split between DPM and RPM, depending on the DPM/RPM ratio plant material.
- Example:
  - **Ag. crops**: DPM/ RPM = 1.44
    - 59% DPM, 41% RPM
  - **Tropical woodland**: DPM/ RPM = 0.25
    - 20% DPM, 80% RPM
  - DPM & RPM ➔ CO2 + BIO + HUM
    - Dependent on clay content
  - BIO + HUM ➔ 46% BIO, 54% HUM
  - BIO & HUM ➔ CO2, BIO, HUM