Project 104(A) Methodology for Assessing Changes in Soil Organic Carbon

The Pennsylvania State University

Project Lead Investigator

Lara Fowler
Professor of Teaching, Penn State Dickinson Law
Affiliate Faculty, Penn State School of International Affairs
The Pennsylvania State University
231 Katz Building
University Park, PA 16802
814-865-4806
Lbf10@psu.edu

University Participants

The Pennsylvania State University (Penn State)

- P.I.s: Lara Fowler, Professor of Teaching, Penn State Dickinson Law; Armen R. Kemanian, Professor of Production Systems and Modeling, College of Agricultural Sciences (starting with funding period beginning December 12, 2024).
  - Researchers: Yuning Shi, Associate Research Professor, Penn State; Emmy Wang, MS Candidate, Agricultural and Environmental Plant Science, Penn State; Alicia Costello, MS Candidate, Ecology, Penn State.
- FAA Award Number: 13-C-AJFE-PSU, RISK-INFORMED ALTERNATIVE JET FUEL (AJF)
- Periods of Performance: December 12, 2024, to September 30, 2026 (time period extended to 2026 through no-cost extension).
- Tasks:
  1. Soil Organic Carbon
     1.1. Work with ASCENT Project 001 team to identify stakeholder engagement opportunities
  2.
     2.1. Complete an analysis of the return of fermentation byproducts to the soil including collaboration with colleagues from Dartmouth College.
     2.2. Analysis of the return of fermentation byproducts to the soil using a carbon balance model and an experimental approach.
     2.3. Apply Cycles-A to the task of fitting sustainable aviation fuel (SAF) crops in the current agricultural matrix of the United States, with focus on oil crops, specifically pennycress, camelina, and *Brassica, carinata* as examples.

Project Funding Level

Federal Aviation Administration (FAA) funding: $163,195 (for December 12, 2024, to September 30, 2026)
Matching from Penn State: $165,814
Total funding: $329,009

Investigation Team

Period July 1, 2023, to September 30, 2026:

- Task 4.1 (Kemanian, Fowler, Wang, & Costello): Accounting for SOC and annual oil crops incorporation using agroecosystem model

Task 1 – Soil Organic Carbon

The Pennsylvania State University

Objective

Incorporate Penn State expertise on soil carbon and nitrogen cycling in the context of the calculation of the carbon intensity of SAF. This includes incorporating carbon cycling modeling and the inclusion of uncertainty bounds, methods for standardizing calculations that encompass baseline (or reference) scenarios and SAF production scenarios. These methods need to be applicable worldwide, but the initial focus is the Contiguous United States (CONUS). In addition, it is expected that similar work accounting for the nitrogen cycle including the carbon footprint associated with the use of fertilizers and an accounting for the emissions of nitrous oxide, whose equivalent carbon footprint can surpass that of soil organic carbon (SOC) both as a positive or negative climate forcing.

Establish the soil carbon balance when amending the soil with byproducts of fermentation for the generation of the alcohol-to-jet (ATJ) fuel. This work will combine experimental and modeling work.

Use an automatic crop sequencer, Cycles-A, to identify opportunities to incorporate oil crops for SAF as winter crops in annual crop rotations across CONUS. The analysis will allow us to access tradeoffs in yield and carbon intensity at the county level. This work contributes to quantifying the uncertainty of fertilization requirements and resulting nitrous oxide emissions, as well as changes in SOC arising from the intensification of SAF production.

Research Approach

The research approach for this task includes developing a standard method to account for land use and SAF production using Earth Stats and level three Global Administrative Areas (GADM) to report calculations on a field basis but also on political units of relevance that are standardized around the world. This task also includes overlaying the North American Land Data Assimilation System (NLDAS) (reanalysis) climate databases, and International Soil Reference and Information Centre (ISRIC) soils, so that the model Cycles (developed in Dr. Kemanian's lab) can be operated through the cropland domain. Finally, this task includes using machine learning combined with a standard initialization procedure to estimate steady state soil carbon stocks under business as usual (BAU) and alternative SAF production scenarios.

Establish both the theoretical framework and model as well as an experimental set up to evaluate the soil carbon balance when the soil is used to produce feedstock for jet fuel. Specifically, we are exploring the path from ATJ fuel, under the assumption that the alcohol is of cellulosic origin and that the fermentation byproducts are returned to the soil.

We will use Cycles-A to generate crop sequences for a representative field from each county for the rainfed area of United States (U.S.). To integrate novel oil crops, we will calibrate a crop profiles using multi-location field trial data and develop a winter-crop phenology algorithm for Cycles-A.

Milestones

The team established a stable database of land use, weather data, and soils, along with automated methods to run simulations with Cycles, and downloaded and curated the U.S. Department of Agriculture-Natural Resources Conservation Service (NRCS) pedon database for machine learning analysis. The team continues systematically updating the information required for a publication reporting expected changes in SOC. The proper allocation of biomass to rainfed and irrigated land, as well as carbon inputs from manure have been resolved. We next aim to obtain accurate estimations of carbon inputs from crop residues.

Additional steps included setting up a soil incubation method to resolve standing questions on SOC storage when amending the soil with byproducts of fermentation.

We also developed an automated mixing model to separate respiration (carbon dioxide [CO_2]) from native soil organic matter and decomposition residue using the isotopic signature. This model, now in a spreadsheet, will allow model inversion via optimization to parameterize the carbon stabilization (SOC storage) parameters.

Finally, we assembled a dataset for winter crop phenology to develop algorithms and parameters to realistically and automatically schedule the planting of winter crops.

Major Accomplishments

Dr. Yuning Shi updated the global weather data from the Global Land Data Assimilation System (GLDAS) reanalysis database, to allow simulation of any crop rotation worldwide. Dr. Yuning Shi and Dr. Armen Kemanian started developing a two-dimensional (2D) version of the model Cycles that will allow simulation of nitrous oxide fluxes in systems with banding of nitrogen fertilizer or manure. Banding is a common practice in crop production. Ignoring nitrogen banding can lead to gross underestimations of nitrogen uptake by crops and alter nitrous oxide emission estimates. The 2D version relies on the use of C-language Variable-coefficients ODE solver (CVODE), a solver for a system of ordinary differential equations maintained by the Lawrence Livermore National Laboratory. So far, water transport in 2D is still being tested, including infiltration that is resolved using a modification of the Green and Ampt method, and water redistribution using Richard's equation. This system will be now incorporated into Cycles-A.

Student Alicia Costello successfully set up an automatic incubation method to measure soil respiration from native soil organic matter versus that from decomposing fresh residues or digestate. The system that is now operational includes retooling an existing CO_2 isotopic analyzer from Picarro, Inc. (Model G2121-i) and adding incubation jars that can be sampled automatically through the incubation period. This experimental setup will provide data of exceptional quality to investigate the carbon balance of soils amended with residues from fermentation in the path from ATJ fuel. The system has been tested and works as expected; it will start yielding results through 2026.

Student Emmy Wang successfully set up and ran Cycles-A simulations at one location using the Penn State Roar Colab cluster (Penn State's high performance computer cluster), successfully generating a response curve about the ratio of pennycress to winter wheat in Darke County, Ohio. For this purpose, Wang created a winter wheat planting and flowering database that was used to modify and calibrate the module handling crop phenology. The phenology module is now generic and includes pennycress as well.

Publications

None. A publication on this topic has been reported through ASCENT Project 001.

Outreach Efforts

Presentations

None. A presentation on this topic has been reported through ASCENT Project 001.

Posters

Costello, A., Montes, F., & Kemanian, A. (2025, October). *Carbon stabilization during incubation of fermentation byproducts* [Poster presentation]. Fall 2025 ASCENT Meeting, Alexandria, Virginia.

Costello, A., Montes, F., & Kemanian, A. (2025, November). *Carbon stabilization during incubation of fermentation byproducts* [Poster presentation]. Science Societies CANVAS conference, Salt Lake City, Utah.

Wang, E., Shi, Y., Fowler, L., Kemanian, A. (2025, October). *Algorithm-based exploration of double cropping with oilseed crops for SAF* [Poster presentation]. Fall 2025 ASCENT Meeting, Alexandria, Virginia.

Wang, E., Shi, Y., White, C., & Kemanian, A. (2025, November). *Algorithm-based exploration of double cropping with oilseed crops* [Poster presentation]. Science Societies CANVAS conference, Salt Lake City, Utah.

Awards

Poster won the 3rd place award for the Climatology and Modeling Section, "Wang, E., Shi, Y., White, C., Kemanian, A. (2025, November). *Algorithm-based exploration of double cropping with oilseed crops* [Poster presentation]. Science Societies CANVAS conference, Salt Lake City, Utah."

Student Involvement

Emmy Wang, MS Candidate, Agricultural and Environmental Plant Science, and Alicia Costello, MS Candidate, Ecology, contributed to this research. Both presented posters at the ASCENT October 2025 Fall Meeting in Alexandria, Virginia; and at the Science Societies CANVAS (formerly Tri-society meeting involving the Agronomy, Crop Science, and Soil Science Society of America in November) 2025 Annual Meeting in Salt Lake City, Utah.

Plans for Next Period

As a joint-effort by the Penn State team working on ASCENT Projects 001 and 104, the top-down modeling of the SOC balance at the county level presented in the ASCENT meeting in Alexandria, Virginia, in October 2024 is being refined and

the results will be summarized in a draft article for publication. Specifically, the analysis to date used SOC from the STATSGO (U.S. General Soil Map) database; it will be replaced (or duplicated) with the global Soil Grids database from the ISRIC. Carbon input, which were estimated using only grain yield and forage yield, will be updated with a longer statistical time series from the National Agricultural Statistical Service and parsed for rainfed and irrigated land, although the analysis will only focus on rainfed soils. As reported before, the analysis has been completed for corn, and we are proceeding with estimates of carbon inputs from other crops. The target journals are *Global Change Biology – Bioenergy* (University of Oxford) and *Energy Advances* (Royal Society of Chemistry). This manuscript will complete the transition of SOC and nitrogen work from ASCENT Project 001 to Project 104.

Experimental and modeled soil carbon balance when adding corn residue to soils as compared to adding high lignin byproducts of fermentation for alcohol or its best known surrogate, digestate that are the byproducts of anaerobic digestion. This task will be part of the MS program of Alicia Costello.

Simulation of oil crops in all areas that include rainfed annual crops using Cycles-A in CONUS. The Cycles-A algorithm finds crop sequences that maximize economic output based on the expected price of grain and forage crops in the menu for a given location, and the cost of production. A system to include weather stochasticity allows generating independent crop sequence for a region that, when analyzed collectively, identify the sequence that maximizes yield or reduces the SAF carbon footprint.