DRAFT for Workgroup Comment (January 22, 2024)

Multi-Model Ensemble Approach to Soil Carbon

Phase 1 Report

Prepared by:

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on behalf of the MME-Soil-C Workgroup

Background

In early 2023, the Conservation Technology Information Center (CTIC), in partnership with Field to Market, launched a new workgroup[1] to begin exploring the feasibility of developing and using an appropriate multi-model ensemble (MME) approach to modeling soil carbon in agricultural systems. As explained in two 2023 blog posts on agclimate.net,[2,3] the workgroup has included the research community, participants in the emerging agricultural carbon marketplace, policy-makers, foundations, and other relevant stakeholders – all led by a small core team[4] who began meeting on a biweekly basis in February 2023. We believe that applying the best available science to this topic will ultimately result in greater accuracy, tighter confidence intervals, and higher payments for producers. Although it has not been the initial target of our workgroup, the same modeling approach should eventually be expanded to include methane and nitrous oxide. The MME approach is initially intended for two specific purposes:

- As a future quantitative measure of soil carbon for the Fieldprint® Platform
- To be available as an alternative method for quantifying soil carbon changes in USDA Climate-Smart Commodity[5] projects

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[1] See Table 1 for a list of all workgroup meeting participants.

[2] Gustafson, D. (2022). "What do Hurricanes and Soil Carbon Have in Common? The Wisdom of a Multi-Model Ensemble Approach," blog on agclimate.net. Published 21-Nov-2022. https://www.agclimate.net/2022/11/21/what-do-hurricanes-and-soil-carbon-have-in-common-the-wisdom-of-a-multi-model-ensemble-approach/

[3] Gustafson, D. (2023). ""Progress in Applying a Multi-Model Ensemble Approach to Soil Carbon" blog on agclimate.net. Published 16-Jun-2023. https://www.agclimate.net/2023/06/16/progress-in-applying-a-multi-model-ensemble-approach-to-soil-carbon/"

[4] Core Team members: Ross Bricklemyer (Bayer), Eric Coronel (Field to Market), Dave Gustafson (CTIC), Ryan Heiniger (CTIC), Ellen Herbert (Ducks Unlimited), Paul Hishmeh (Field to Market), Jeff Lail (Syngenta)

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[5] https://www.usda.gov/climate-solutions/climate-smart-commodities

Both of these applications have a US-only focus – thus the approach is not initially intended for use in global initiatives (e.g., SBTi,[6] GHG Protocol,[7] or carbon registries). However, the workgroup has included sufficient global representation such that consistency and the possibility of future applications of the approach in such domains are both maintained.

Such an ensemble approach has ample precedent in modeling other complex processes, such as global climate modeling, weather forecasting, projecting hurricane trajectories, and (perhaps of greatest relevance) predicting crop yields. As demonstrated by the Agricultural Model Intercomparison & Improvement Project (AgMIP),[8] the median of an MME gives better predictions than any single model. See the References listed at the end of this report for more detail on this topic, especially Riggers et al., 2019.[9] In addition, such an MME approach was endorsed by at least three organizations (IL Soy, Regrow, Woodwell) in their public comments posted in response to the recent NRCS Request for Information on implementation of Inflation Reduction Act funding.[10]

Our workgroup has identified two desired deliverables, the second of which will certainly require an infusion of new funding (after Phase 1), most logically from a public source:

- A peer-reviewed article in a first-tier journal showing the benefits of the MME approach
- An Application Programming Interface (API, free to anyone) that allows any interested party to deploy the MME approach (which helps address fundamental equity issues in the emerging climate-smart ag marketplace)

Our workgroup has the following guiding principles:

- We encourage participation from all private and public sector modeling teams.
- The MME-based API should be based on individual models that are each "publicly available, documented transparently, and based in peer-reviewed literature whenever possible." (this language is taken directly from the USDA Climate-Smart Commodity Partnerships RFP[11])

[6] https://sciencebasedtargets.org/net-zero
[7] https://ghgprotocol.org
[8] http://www.agmip.org
[9] Riggers, C., Poeplau, C., Don, A., Bamminger, C., Höper, H., Dechow, R. (2019). Multi-model ensemble improved the prediction of trends in soil organic carbon stocks in German croplands, *Geoderma*, 345:17-30. https://doi.org/10.1016/j.geoderma.2019.03.014
[10] https://www.nrcs.usda.gov/news/usda-requests-public-input-on-implementation-of-inflation-reduction-act-funding
[11] https://www.grants.gov/web/grants/view-opportunity.html?oppId=337878

- The MME-based API should require no more information than is currently required by the Fieldprint Platform.

At the outset, the workgroup adopted a phased approach to its work. Phase 1 has been primarily focused on outreach to the technical community and evaluating the feasibility of the proposed API. The technical outreach component has always included the idea of a peer-reviewed publication, which we subsequently learned is under preparation by Dr. Bruno Basso (Michigan State University), as explained in greater detail below. The other Phase 1 deliverable is this report, which is focused on validation of the overall MME concept and development of recommendations for operationalizing and sustaining the proposed API.

Workgroup Activities

The workgroup held its initial meeting on March 21, attended by about 30 members of this emerging community, including leading public and private sector teams, e.g., USDA/NRCS, Indigo, Regrow, HabiTerre, and Nori. The workgroup's guiding principles and deliverables were broadly endorsed as being both achievable and valuable for building trust and credibility, qualities that have fallen prey to skepticism in certain corners of the climate-smart ag marketplace. Also at the March 21 meeting, workgroup member Dr. Bruno Basso (Michigan State U) reported that he was working on a publication in which he would describe a shareable tool that runs an ensemble of seven leading soil carbon models, all meeting the public availability criterion described above.

On April 25, Dr. Gustafson presented this work at EGU23 (Vienna), where he learned that there is apparently no comparable effort underway in the European context, nor any obvious global collaborators, with the possible exception of a modeling team at Rothamsted, who subsequently received workgroup communications and participated in the Phase 1 close-out meeting, held on December 19 (see below).

On June 6, workgroup core-team members gave an update in the form of a panel presentation at the Field to Market Plenary in St. Louis. The diverse, multi-sector audience included farmers, industry, researchers, and government scientists. They expressed keen interest and we heard a strong sense of urgency to make an API available as soon as possible, so that these more accurate calculations can be utilized in the many climate-smart ag projects that are now launching on millions of acres of farmer fields nationwide. They endorsed the idea that the initial

focus should be on the large acre row crops covered by Field to Market, but that future releases of the API should target future applications in grazing lands, rice, orchards, and other specialty crops.

Dr. Basso presented on his MME work at AgMIP9,[12] held June 26-30 at Columbia University (New York City). Dr. Gustafson also attended AgMIP9, where he participated in a small-group discussion on Dr. Basso's work and invited additional participation in our workgroup. USDA's Bill Hohenstein gave a presentation at AgMIP9 in which he highlighted the ensemble approach as one that USDA considers to be an important research topic.

In August 2023, CTIC submitted public comments to USDA/NRCS in response to their request for information on its "Federal Strategy to Advance Greenhouse Gas Emissions Measurement and Monitoring for the Agriculture and Forest Sectors," (USDA's "MMRV Strategy") released for public comment on July 12, 2023. The comments were on three topics, the first of which was this MME workgroup effort. The comments expressed strong interest in partnering with USDA and other interested parties on the development of an MME-based API for soil carbon, such as by helping to draft an appropriate Request for Proposals (RFP) to further development of such an API, and/or by serving as a partner to provide feedback on the API as it is being developed.

The Field to Market staff science team briefed its Board of Directors in October 2023 on efforts to revise their soil carbon metric. Subsequent presentations on this were made in December 2023 on this topic to the full Metrics Committee and plenary membership. To address near-term membership requirements for a quantitative soil carbon metric, Field to Market is planning to move forward with a single model approach at this time, most likely based on SWAT+.[13] However, an MME approach is still viewed as a viable and important effort, and interest in collaboration and potential adoption of the MME in the Fieldprint Platform remains strong.

NRCS's Dr. Laura Schreeg made public comments strongly supportive of an MME approach during a stakeholder meeting held in DC on November 7, attended by both Paul Hishmeh and Dr. Gustafson. During conversations held with her there, we learned that Dr. Schreeg had attended Dr. Basso's presentation on his MME approach at the Tri-Societies meeting (October 31, St. Louis) and was interested in learning more about it. Dr. Basso was subsequently invited by NRCS staff to have follow-up conversations where there were expressions of continuing interest.

[12] https://agmip.org/agmip9/
[13] https://swat.tamu.edu/

Dr. Gustafson met with Dr. Basso at AGU (December 14, San Francisco), where Dr. Basso agreed to present the status of his work to the full workgroup at its "Phase 1 Project Close-out Zoom meeting," held on December 19. One of the points that Dr. Gustafson emphasized with Dr. Basso is that the API be fully interoperable with the constellation of other relevant tools (e.g., the National Calibration Dataset) that are now in various stages of development to support the emerging climate-smart ag marketplace. Dr. Basso fully embraced this suggestion and incorporated it into his presentation.

The December 19 workgroup meeting was not recorded, but the slide sets used by Dr. Gustafson at the meeting to summarize Phase 1 findings and resulting feedback have been distributed to all meeting participants. The draft key findings from Phase 1 that were presented to the full workgroup on December 19 are summarized below, followed by a summary of the feedback received from the full workgroup during and after the meeting.

Key Findings from Phase 1

1. Bruno Basso has made excellent progress on a viable MME approach to modeling soil carbon, which he plans to publish.
2. He has proposed a process for development of an API based on publicly-available models and free to use.
3. It is important to ensure that the API is fully interoperable with the Fieldprint Platform and other relevant tools & datasets (e.g., the National Calibration Dataset).
4. There is a continued role for the MME-Soil-C Workgroup to ensure the proposed API will meet user needs.

Feedback from the Full Workgroup

During the December 19 meeting, three questions were asked of the workgroup participants:

1. *What changes in functionality are needed for Bruno's proposed API?*
2. *What changes in the proposed implementation process are needed for the API?*
3. *Is there a conditional consensus to support development of the API, as modified?*

The workgroup began answering these questions while Dr. Basso was still on the call, and then continued the discussion after he dropped off, as planned. In addition, Dr. Gustafson received

additional feedback from workgroup members after the December 19 meeting. All of the feedback received thus far is summarized below. Future drafts of this document will incorporate any additional feedback. Proposed answers to the various italicized questions are addressed via the answers provided in the "Recommendations for Phase 2" section that concludes this document.

Overall Feedback

- Concerns were expressed by some about the GHG Protocol, SBTi and related initiatives, from those who question whether an MME approach will be adoptable in those contexts.
    - *Is this really a killer issue? We had previously said it shouldn't stop us.*
- The priority of developing an MME-API[14] was questioned by some workgroup members vs. other issues that they saw as being potentially more important, in terms of the overall MMRV strategy. Here were some of the issues that were mentioned:
    - Test and improve individual models
    - Engage companies to collate soil sampling data
    - Leverage existing remote sensing data to fill data gaps
- Timelines have already been slipping and getting funding for API development will likely bring further delay, all at a high environmental cost. Humanity generates 0.14 Gt CO_2e each day. It takes ~400M acres of cover crops to capture that much C in one year. For mitigation to be effective, it must be fast. *Given all this urgency, is an API the next step?*
    - Related concern: The far bigger mitigation opportunity in US croplands is N_2O, not C. *Is an API that doesn't handle N_2O worth the effort?*
- Despite the above questions, there is support for developing a prototype of the proposed API now, subject to additional questions listed below

Specific Questions about the Proposed API

- Is it reasonable to use uncalibrated models?
- Should individual models remain unidentified?
- Are these the right models? What about DNDC, other "real" biogeochemical models, and additional more modern approaches (e.g., models based on ML, etc.)?

[14] For simplicity, the remainder of this document refers to the proposed API for implementing an MME as simply "the API"

- Should API development and implementation be left within a single academic institution vs. a partnership involving a commercial software vendor?

Recommendations for Phase 2

Despite some of the challenging feedback received from certain workgroup members, we believe that there is sufficient support for the development of a prototype API at Michigan State University, as proposed by Dr. Basso. We encourage USDA/NRCS to provide sufficient financial support to enable such development to proceed. Dr. Basso's proposal that API development could proceed in parallel with his planned publication seems reasonable to us, given the urgency for making progress in this important area. However, we also believe that some form of our current workgroup should continue during Phase 2, in order to ensure that user needs are being fully met (e.g., help define API specifications for input data requirements, for interoperability, etc.). We also believe that the following issues should receive strong consideration as the prototype is developed.

Model Calibration: While we see it as acceptable for the prototype API to continue to rely upon uncalibrated models, we believe it may be necessary to revisit this issue if the API were to become fully operational in the emerging climate-smart ag marketplace. Given the continuing dynamic nature of that marketplace, it is not currently possible to anticipate what future constraints will become a practical necessity. This ongoing uncertainty is one of many reasons why it will be important to leave a version of this current workgroup in place.

Individual Model Anonymity: Multiple workgroup members indicated their strong preference for the individual models within the MME to be identifiable. This runs contrary to Dr. Basso's preference. We believe it would be acceptable for development of the prototype to proceed with Dr. Basso's preferred approach of preserving model anonymity, but we believe this falls in the same category as calibration, i.e., an issue that will need to be revisited if and when the API becomes operational.

Choice of Models to Include in the API: The current suite of models chosen by Dr. Basso is not comprehensive and it will be important to include as many of the leading biogeochemical models as is practical. Again, for the purposes of the prototype it is likely acceptable to not include models such as DNDC, *ecosys*, or SWAT+ – but all three of these are leading examples of important models that should receive strong consideration for the operational API. There are likely some other strong candidates now and it seems inevitable that even more models are likely to

emerge in the future. It would be ideal for the API to be designed such that adding more models will be as efficient as possible.

Nitrous Oxide: As noted above, N_2O represents a far larger climate mitigation opportunity than soil carbon in US croplands. We find it acceptable for the prototype to focus only on soil carbon, which had been earlier agreed by our workgroup as the most logical first step. But there are many workgroup members who questioned the value of an operational API that does not address this important GHG. The same could be said for methane in animal and rice systems, but these latter two use cases are of less current interest than the major row crop systems that are the focus for most workgroup members (e.g., corn, soy, wheat, etc.).

Additional Considerations for the Operational API: Workgroup members with expertise on API development proposed that it would be acceptable for development of the prototype API to proceed at Michigan State University. However, they also stated that it will then be far preferable for development of an operational version of the API to be transferred to an appropriate private-sector developer having the requisite internal resources and relevant business expertise. There are also concerns about the likely complexity of licensing, IP, etc. associated with both the API and the individual models within the MME. The concern over these complexities is significantly lessened by the fact that Dr. Basso has included only publicly-available models in the MME, but this entire domain is fraught with potential pitfalls that we should do our best to anticipate and avoid. It would be prudent for the workgroup to cultivate a relationship with an appropriate IP legal expert who could provide timely input and advice as Phase 2 proceeds.

Table 1. MME-Soil-C Phase 1 Workgroup Meeting Attendees

Dave Gustafson	CTIC	Co-Lead	Shuting Zhai	Nori	Attendee
Paul Hishmeh	Field to Market	Co-Lead	Dorn Cox	OpenTEAM	Attendee
Ross Bricklemyer	Bayer	Core Team	Anastasia Volkova	Regrow	Attendee
Ryan Heiniger	CTIC	Core Team	Curtis Jones	Regrow	Attendee
Ellen Herbert	Ducks Unlimited	Core Team	Gayathri Gopalakrishnan	Regrow	Attendee
Eric Coronel	Field to Market	Core Team	Janet Smith	Regrow	Attendee
Jeff Lail	Syngenta	Core Team	Katelyn Dolan	Regrow	Attendee
Alex Ruane	AgMIP	Attendee	William Salas	Regrow	Attendee
Terry Nipp	AgMIP	Attendee	Marcelo Galdus	Rothamsted	Attendee
Lacey Pyle	Arva	Attendee	Jens Kiesel	Stone Env'l	Attendee
Sharon Bard	Consultant	Attendee	Ben Harris	Sust. Food Lab	Attendee
Jane Zelikova	CSU	Attendee	Jason Neff	Syngenta	Attendee
Keith Paustian	CSU	Attendee	Liz Hunt	Syngenta	Attendee
Jocelyn Lavallee	EDF	Attendee	Luca Doro	Texas A&M	Attendee
Kenny Dhakal	Enriched Ag	Attendee	R (Srini) Srinivasan	Texas A&M	Attendee
Mike Komp	Enriched Ag	Attendee	Adam Herges	The Mosaic Co.	Attendee
Chris Smallwood	ESMC	Attendee	Negar Tafti	TNC	Attendee
Kathy Boomer	FFAR	Attendee	Kaiyu Guan	UIUC/HabiTerre	Attendee
Austin Pearce	Field to Market	Attendee	Guanyuan Shuai	UMD/NASA	Attendee
Zoe Amerigian	GEVO	Attendee	Ritvik Sahajpal	UMD/NASA	Attendee
Kuang-Yu Chang	HabiTerre	Attendee	Prasad Bandaru	USDA/ARS	Attendee
Brian Fischer	Houston Eng.	Attendee	Steve Mirsky	USDA/ARS	Attendee
Drew Kessler	Houston Eng.	Attendee	Adam Chambers	USDA/NRCS	Attendee
David LeBauer	Indigo	Attendee	Laura Schreeg	USDA/NRCS	Attendee
Rebecca Keating	Indigo	Attendee	Claudio Stöckle	WSU	Attendee
Bruno Basso	MSU/CIBO	Attendee			

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