INSTITUTE for CARBON REMOVAL LAW AND POLICY

Assessing views on soil carbon in croplands: Final report

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Executive Summary

The aim of this project is to assess the agreement amongst scientific and civil society communities on the potential for soil organic carbon (SOC) and the potential for soil carbon sequestration in croplands as a climate mitigation strategy. Participants for this study were selected from leading environmental organizations and academic institutions actively working on soil carbon issues. This study limited its scope to soil carbon in croplands that are intended to remain croplands, while taking into consideration net greenhouse gas (GHG) mitigation that result from specific management practices.

These efforts were conducted in four phases utilizing a modified version of the Delphi method: semi structured interviews; online surveys; a virtual workshop; and analysis and interpretation. Of these, 65 individuals were administered a survey, 27 were invited for full participation via an invitation for a semi structured interview and participation of the workshop. Of these 8 participated in an interview and 11 participated in some or all of the workshop. Of the workshop participants, 1 individual was included as a replacement per the recommendation of a participant who could not attend the workshop, therefore was not included in the invitation to interview.

The findings of this study covered a range of topics related to SOC, including biophysical factors, technical potential, the feasibility of potential, sources of information trusted by participants, socio-political considerations, and carbon market considerations. Through this process, the Project Team tasked with conducting this study was able to develop a set of testable statements through collaborative efforts from all participants attending the workshop. These statements were then subsequently administered to the wider pool of participants in a follow up survey to gauge levels agreement after the conclusion of the workshop. Upon conclusion of this study, the Project Team was also able to identify strategic considerations for advocacy going forward, and implications for future research.

There were several areas relating to the science and understanding of processes that affect soil carbon in which there was a relatively high level of agreement among the study participants, particularly those in the workshop. These areas include: the scientific understanding of these processes is sufficient to support action; the scientific understanding capability in predicting SOC outcomes to inform policy and carbon markets; the need for research expansion to cover under-studied aspects of SOC; and the need for inclusion of social scientists which were under-represented in this study.

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Participants saw value in the production of an authoritative document or report that sums up the state of the science from a widely respected scientific body to aid in the understanding of SOC outside the scientific community. Such a product would be intended to mitigate the unbalanced perception of soil carbon potential and interventions that are not sufficiently supported by science by stakeholders and civil society outside the scientific community.

Furthermore, many scientists in this study believe soil carbon dynamics under real field conditions, rather than experimental conditions, have not been studied adequately. They emphasized that future work should include viewpoints from farmers and other stakeholders, through dialogues that included both scientists and practitioners, and pursuit of a research agenda that looks at real-world situations in which soil carbon interventions would be tested.

We also found that the scientific community feels a disconnect between themselves and the policymakers who are making decisions that affect soil carbon. This left the impression that scientists feel that their collective perspective is being drowned out in policy discussions, both by unsupported exuberance and by counterproductive skepticism. On the final day of the workshop, participants expressed concern that the scientific community is to some degree sending mixed signal on these issues; with some doubting the potential of SOC to make a significant difference in climate mitigation and the others advocating for investment into SOC of it's potential to deliver other co-benefits that are difficult to achieve through other means. Although the Project Team did aim to rectify these differences and gain some common ground, in reality many of these debates can only be resolved in the context of a concrete policy design process.

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Introduction

Background & Study Objectives

The aim of this project is to assess the level of collective understanding and agreement amongst the scientific and environmental NGO community on the potential for soil organic carbon (SOC) to deliver greenhouse gas (GHG) sequestration within agriculture croplands. The project team has worked to elicit input and insight from a range of subject-matter experts. This report summarizes the study process, key findings, and plans for future work.

From the outset, the focus of this study was on the U.S. context, though our intention has been to consider global perspectives as much as possible. Participants for the study were selected from leading environmental organizations and academic institutions. The Project Team aimed to identify participants according to the following criteria: 1) actively conducting research relevant to soil carbon, as evidenced by authorship of recent publications; 2) advocates likely to influence the development of U.S. policies related to agriculture, as evidenced by recent positions or projects; or 3) experts at organizations or institutions already working in this area, identified through relevant networks, including through EDF's scientists. Where possible, we sought to include experts who were known for their open-mindedness and willingness to engage constructively in dialogue about this topic.

This phase of the multiyear study was designed to establish a baseline, assessing the degree of agreement across these experts about key issues related to soil carbon. Later phases of the project will work to build consensus within the scientific and NGO community. From this phase, the Project Team aimed to identify where these communities could agree on the importance of key topics, areas of future research, and considerations for advocacy that have the potential to affect the issue of soil carbon in agriculture in the future.

Study boundaries and topics of interest

The scope of this study was primarily aimed at assessing soil carbon in croplands that are intended to remain croplands, while taking into consideration net greenhouse gas (GHG) mitigation that result from specific management practices. The importance of counting net GHGs was recognized by all participants as a key factor in determining mitigation potential. Furthermore, we did not directly consider land-use change or the fallowing of active cropland. The principal focus of our work was practices that could be implemented in annual cropland agriculture, with the aim of maintaining productivity while also sequestering carbon. We

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included (but limited our consideration of) conversion from annual to perennial crop systems. We did not consider the potential for introducing trees or other perennials into the cropland system (e.g., through windbreaks, intercropping, etc.), nor did we explore the potential introduction of livestock into the crop system, even though this is a common practice in some parts of U.S. and throughout the world.

The geographic scope of our study focused on the continental U.S., though we and the participants took steps to include globally relevant research and perspectives. In the end, our pools of participants and literature were heavily weighted toward the U.S. context. The Project Team took this into consideration, shared this fact with all participants, and asked participants to indicate when their responses or contributions applied to a different context.

Overview of study process

This study was conducted through four main processes:

1. Semi-structured interviews
2. Online Survey(s)
3. Virtual Workshop
4. Analysis and interpretation

These four elements comprised a modified version of the Delphi Method, as a process for testing expert opinion and levels of agreement on specific statements. The processes were generally implemented in sequence, with some overlap and ongoing interpretation and learning. We ensured that the results of the first two processes (i.e., interviews and survey) were taken into account in the design of the workshop. The interviews and literature review were used to inform the first round survey questions and 'testable statements' shared with survey respondents. The results of the survey were then shared with workshop participants for feedback, discussion, and clarification, especially in further refining a set of testable statements that could be further tested in a second round survey. More detail on each of these components is outlined below.

Semi-Structured Expert Interviews

The Project Team worked with EDF colleagues to identify a set of priority participants for the workshop and survey. Based upon that list, the Project Team invited 27 individuals for an interview and was able to conduct 8 semi-structured virtual interviews with experts in this field. The 27 participants invited for the full participation of this study (interview, survey and workshop) can be found within the contact list under Appendix B listed as "Priority A."

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The primary objectives for the interviews were to:

- identify participants' relevant knowledge and experience on issues related to soil carbon sequestration;
- to understand how each participant's viewpoints compared to other respondents and recent academic literature;
- to understand whether and how their views have evolved over time;
- to identify relevant nuances or factors that could change with new information, where they might disagree with the balance of the relevant literature or colleagues, and where gaps and needs for further research to clarify points of uncertainty.

Secondary objectives of the semi-structured interviews were to elicit information on: 1) key unresolved issues relevant to soil carbon in croplands; 2) views about the prioritization of soil carbon consideration in research and policy, including whether priorities should change; and 3) how these issues might be organized and addressed through a coherent research agenda. The information gathered from the interviews was combined with a literature review undertaken by the Project Team and discussions with EDF colleagues to inform a first set of survey questions, which was administered in advance of the workshop.

Survey Development

Based upon the expert interviews, the Project Team developed a set of survey questions and testable statements. The testable statements were designed to test each participant's level of agreement or disagreement with statements, concepts, or priorities reflected in recent literature and policy debates. In keeping with the Delphi method, these statements were intended to elicit expert opinion, not test knowledge of scientific facts. As such, each statement contained a position on an issue related to soil carbon sequestration, for which we asked survey respondents to offer their reactions, ranging from strong agreement to strong disagreement.

The survey also contained other types of questions. The draft survey questions were shared with EDF colleagues for review, and their feedback was incorporated in the version administered to participants.

The online survey was administered to 65 individuals (Appendix B), based upon the list identified by the Project Team and EDF at the start of the project. Of those invited to participate in the survey, 31 responded. Results from the survey were analyzed and shared with the workshop participants for discussion and feedback.

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Virtual Workshop

The Project Team convened a virtual workshop conducted over three days, with two 90-minute sessions on each day. This format was selected to minimize participant fatigue and to encourage diverse participation across varying time zones. Of the 27 participants invited to participate, 11 participants joined for some or all of the workshop.

The first day of the workshop included a presentation of the survey results with the highest degrees of convergence (agreement) on the survey responses to questions and testable statements. The agendas, both original and revised, can be found in Appendix A. Following the presentation, participants were given the opportunity to share their insights and observations on the results, including suggestions for improving the survey questions and testable statements for future surveying. This approach allowed for participants to explore and discuss the topics at hand, fostering greater understanding of each other's perspectives, and the spectrum of views across the field. It also allowed the Project Team to gather information on how to refine and strengthen the testable statements in future surveys to yield more accurate results–and perhaps identify areas of even higher degrees of convergence.

This process was repeated for the second day of the workshop, which focused on areas of medium convergence – or where the survey results showed a dominant view with a range of minority views on the topic. This workshop discussion was aimed at testing and understanding the boundaries of expert opinion and clarifying areas of convergence and divergence. For example, an area of divergence could have been because two survey respondents interpreted the question or statement differently, not due to substantive disagreement. Therefore, the workshop discussion was very helpful for exploring and unpacking terminology and the range of perspectives. This also helped inform refinements to a set of testable statements to be used in future surveys.

The third day of the workshop was intended to explore areas of low agreement; that is, where survey results indicated two divergent, strongly held viewpoints among participants about a particular statement or issue. However, in response to the dynamics of the first two days, and in consultation with EDF leads, we changed the format of the final day. Instead of exploring areas of low convergence, we worked interactively with the participants to refine a set of statements that they felt were more precise and could potentially garner wider agreement among our key audiences. These statements included a chapeau that would provide context for all of the statements that followed. The chapeau and refined statements were then further clarified by the Project Team and EDF staff, to be used as a basis for a second survey.

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Analysis and Interpretation

Analysis and interpretation was an iterative, ongoing process throughout the course of the study. This included analysis of the literature, the interview results, and interpreting that data to inform the set of first round survey questions. The Project Team and EDF leads compiled and discussed this information in preparation for developing the workshop presentations, agenda, and discussion questions. Throughout the study, the Project Team drew upon their methodological and subject-area expertise to further the iterative nature of the modified Delphi method, utilizing the ongoing inputs from study participants and respondents. While the process was unique in its specifics, the Project Team believed the iterative and interactive nature of the process would yield comparable results with the same or a similar group of participants in the future. Throughout the process, the Project Team consulted regularly with EDF colleagues and incorporated their thoughtful, expert feedback.

Key caveats and limitations

Although a robust list of study participants was identified and vigorous outreach to engage these individuals in this study was conducted, the Project Team did face some challenges that arose, primarily, from limited participation. This may have been due to the timing of the study, which was conducted during the holiday season and immediately following the COP26, so many of our intended participants indicated a lack of time and bandwidth to participate. Other factors to consider include the ongoing pandemic, significant general burnout and Zoom fatigue, and the inability for participants to meet in a face-to-face setting. Given these considerations, the sample size of this study was smaller than hoped, yielding greater uncertainties and less statistical power in analyzing results. Furthermore, we noted that some individuals declined to participate, stating that they felt they would not be in agreement with the majority of the participants or with views they perceived EDF to hold as an organization. Their absence from our participant pool may have introduced selection bias in our findings and limited the diversity of viewpoints about our chosen topics.

In the face of these limitations, it was necessary for the Project Team to be adaptable throughout this study. In addition to the logistical challenges of participant availability, time of year and running a workshop that catered to busy schedules and time zones, the scope of the study also shifted slightly as the project progressed.

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Findings

Biophysical factors and technical potential

In interviews, survey results, and the workshop, participants expressed a high degree of comfort with characterizing soil carbon sequestration as a beneficial component of soil health, rather than a desirable end in itself. For instance, 90% of survey respondents agreed with the statement "Promoting soil carbon sequestration for soil health has multiple social, economic, and climatic co-benefits," and the remaining respondents neither agreed nor disagreed. Soil health became a key theme in workshop discussions – a theme that garnered widespread support. To the extent that biophysical and technical potential factors affecting soil carbon were strongly associated with soil health, participants expressed a willingness to promote soil carbon sequestration. They largely agreed upon that soil health should potentially be the main rationale for improved management practices, with soil carbon as an important indicator and climate mitigation as a potential co-benefit. Importantly, participants emphasized the need to track fluxes of all greenhouse gases associated with management practices in croplands and noted that consideration of soil carbon alone could fail to accurately quantify the climate effects of cropland management. Since most methodologies for quantifying GHGs associated with cropland management require comprehensive consideration of all gases, it comes as no surprise that these experts would make note of this as a technical point. Their assertion of this widely accepted, fundamental consideration might indicate a fear among experts that other audiences – such as policymakers and producers – are not aware of this basic requirement.

A second fundamental consideration emphasized in interviews and the workshop (and supported by survey results) was the importance of soil sampling as the most reliable means of quantifying soil carbon at all scales of estimation. Participants emphasized the spatial and temporal variability of processes that affect soil carbon in croplands, as well as the variability in its response to management practices. Soil sampling was seen by the majority of participants as the most appropriate basis for setting baselines for soil carbon and measuring changes over time. Other techniques, such as measurement and modeling based on proxy variables and remote sensing data, were seen as useful ways to supplement and extend (but not replace) the usefulness of sampling data.

Participants emphasized that soils are comprised of living systems that are constantly changing due to external conditions and internal processes. This point is sometimes difficult for other stakeholders to grasp, particularly when they want to obtain predictable and quantifiable results from specific interventions.

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Despite the variability and dynamism inherent in cropland systems, participants and the reviewed literature were in agreement that the relationships between biophysical conditions, management practices, and soil carbon are sufficiently known to be able to predict directional changes reasonably well. In many cases, the quantitative change in soil carbon can be predicted within reasonable ranges of certainty for most locations (in the continental U.S.) and for the most common individual management interventions. On the other hand, combinations of approaches and less common interventions have not been studied as completely, and most participants agreed that this would be a fruitful area for further research.

Feasibility of potential

Participants displayed a range of views about the political, social, and economic feasibility of delivering the technical potential for increasing soil carbon. A majority of survey respondents (~60%) said that less than half of the technical potential was politically and socially achievable within 10 years. Interestingly, views were split about the economic feasibility of mobilizing this potential: nearly equal numbers said "a large majority" and "a small minority" of the potential was economically achievable in 10 years, even though they had a high level of agreement about the overall scale of the technical potential. The Project Team's interpretation, based on interviews and the workshop discussions, is that the participants have varying degrees of faith in the success of economic, political, and social factors in triggering changes in cropland management. That is, their range of views is due to different expectations about the relative significance of these factors in affecting cropland management changes, not in different expectations about the achievability of soil carbon increases. The Project Team noted that knowledge of social science issues was outside of the range of expertise of most of the participants, who tended to have backgrounds in soil science, agronomy, and biogeochemistry. Thus, the Project Team does not interpret these results as a definitive statement about feasibility – rather, they might best be interpreted as a reflection of the lack of relevant expertise among this particular group of experts. Put simply, this may be a case where the right questions may have been posed to the wrong experts. Therefore, the Project Team urges caution in interpreting these results.

In line with this interpretation, the participants expressed a range of potential interventions for affecting the economic, social, and political factors that could, in turn, affect soil carbon. These interventions ranged across all aspects of the cropland agricultural system and varied from quite general to highly specific. An illustrative sample of suggested interventions from individual survey participants is listed below:

- "A combination of barrier removal … marketing … and incentives"

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- "Reform banking and crop insurance protocols to allow alternative farming methods to be accepted and implemented"
- "Payments for carbon storage"
- "Major re-education of farmers across the central US"
- "- more support for farmers to adopt improved practices
  - continued research that is regionally tailored …
  - proactively addressing obstacles
  - ensuring that new supports/research address … uncertainties
  - prioritize practices/systems that help with climate change adaptation and other environmental and social challenges"

The significance of soil carbon as a contribution to overall efforts to mitigate climate change was a theme that triggered debate within the workshop. One side of the debate felt that the potential deliverable scale of soil carbon sequestration would not be climatically significant and would not justify a dedicated effort to promote investments and policy changes aimed at increasing soil carbon in croplands. "If we can draw down carbon dioxide in the atmosphere in a measurable way, then that's worth the effort… [but] if we're promoting the expenditure of time, energy and billions of dollars to not, in the end, affect the atmosphere at all, it's irrelevant," was said by one. On the other side, some participants emphasized that each increment of improvement in soil carbon has a small impact on climate mitigation and therefore is worth pursuing as a component of an overall mitigation portfolio. These participants seemed to want soil carbon to be evaluated by its cost-effectiveness in delivering mitigation (and other co-benefits), rather than on the overall scale of its potential. This debate was not strongly polarized within the workshop group, and many individuals seemed open to either argument, without expressing a strong emphasis on one or the other.

This particular debate surfaced at least four distinct and relevant viewpoints:

- Why bother if it's insignificant (to climate mitigation)?
- The measurement protocols are already in existence, so if there is any carbon storage occurring, then we should pursue it.
- There is a need to look beyond carbon and into other benefits of management practices.
- SOC is not the correct place to be focusing our attention and we should be focusing on other dimensions of soil.

The lack of convergence about the potential for mobilizing soil carbon sequestration sparked concern from one participant, who stated "if we can't agree in this fundamental tenant that

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there are levers we can pull to get more carbon in the ground, aside from the policy questions that remain…then we are dismissing the huge body of literature that points to the potential…."

When we came to the challenge of linking soil carbon outcomes to specific practices, the experts reinforced our interpretation from the literature; namely, that rates of carbon increases are far too nuanced and varied across different geographies to reliably predict the quantity of sequestration that would occur due to any particular agricultural management practice. The effect of practices cannot be divorced from the context in which they occur. One such example that was referred to on this point was no-till, which in some cases can actually be ineffective in enhancing carbon sequestration due to a combination of high moisture and carbon saturation levels. In such circumstances, the best outcome for carbon sequestration could involve increasing the depth of tillage to reach soil horizons where the stabilization capacity is greater. On the other hand, many participants agreed that, even though knowledge about these nuances of soil carbon and management practices is not perfect, certain reliable principles could help guide a general understanding of the conditions under which practices can be effective in increasing soil carbon. Most felt that these factors were sufficiently well understood in most geographies and contexts to be able to reliably recommend management changes that would move soil carbon in a beneficial direction, even if the exact scale of the effect could not be predicted with reasonable precision.

These findings may be consequential for policymakers. In the Project Team's interpretation, the experts would be comfortable with policies that encourage the uptake of particular practices, especially if they can be tailored to geographies and production types. However, the experts were not comfortable, in general, with linking incentives directly to site-specific, quantified estimates of soil carbon increases (unless these increases were measured through soil sampling). The statistical and probabilistic relationship between practices and soil carbon outcomes, combined with the heterogeneity of biophysical conditions and the costs of soil sampling, mean that performance-based incentives may be out of reach for the foreseeable future.

Although some participants voiced strong skepticism about the narrative that soils have the potential to "save us from climate change", many also expressed optimism about how the focus on soil carbon and climate change mitigation has shifted the overall conversation about where our food comes from, shedding light on the associated impact of our food systems on the environment

In terms of the extent of mitigation potential, one of the survey results utilized as a discussion point for one of the workshop sessions was telling. The original statement in the survey was:

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"The potential for increasing SOC occurs in only a relatively limited set of geographies or a limited set of biophysical conditions," which resulted in 71% disagreement from all respondents. However, when this statement was revised according to discussion and revisited later on during the session to: "The practical potential (considering socioeconomic, policy, and culture) for increasing SOC is widespread across diverse geographies and biophysical conditions," there was general agreement from the group. Our key takeaway is that participants share a level of agreement about the relatively widespread availability of potential to increase soil carbon. Again, we see implications for policy-making, and we confirmed this during the workshop: activities and policies aimed at increasing soil carbon may be more likely to succeed if conducted broadly, perhaps in conjunction with existing federal policies, rather than narrowly tailored to specific locations or types of management.

Overall, in spite of general convergence about high-level statements, we found the expert consensus to be somewhat superficial on topics related to soil carbon sequestration. Where discussions and statements became more detailed and nuanced, workshop participants indicated a range of perspectives and lacked a shared opinion on the topic. To further understand the boundaries of convergence among experts on this topic, it will be necessary to dig into the details and particulars of questions at hand. The workshop was a valuable starting point for those discussions and it illuminated some research questions to explore that could further collective understanding and agreement.

Information sources and socio-political considerations

Our survey gathered responses about the most trusted sources of information for the respondents themselves, as well as the sources that respondents believed were most trusted by scientists, influential advocacy organizations, and farmers. The juxtaposition of responses between scientists and farmers was striking. For the scientists, respondents almost exclusively indicated sources from within the research community, such as peer reviewed literature and fellow scientists. However, the responses also overwhelmingly indicated a shared belief that the most trusted sources for farmers came from outside the research community, such as consultants and crop advisors, input sellers, and fellow farmers. Views about the most trusted sources for advocacy organizations suggested a mix from inside and outside the research community. In our interpretation, this could suggest that advocacy groups may have an important role to play as boundary organizations between the research community and implementers.

Survey results indicated that there are a number of economic, political and social factors that could be altered to enhance the ability of realizable potential of soil carbon. Among those,

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respondents indicated factors such as reeducation of farmers, research that is regionally tailored, and ensuring new support and research efforts address remaining uncertainties. These qualitative responses, and the ensuing discussion in the workshop, suggest that economic and technical assistance may be needed for realizable increases in soil carbon stocks.

Discussion in the workshop of socioeconomic themes and their implications for soil carbon revealed varied opinions, with a shared view that the influential actions would be implemented as a reflection of societal desires and priorities, rather than on any potential breakthroughs in science. In this respect, the relatively low representation of social scientists among the participants meant that our discussion lacked the kinds of formalized and theory-based understanding that social scientists could have brought to our conversations. Nevertheless, identifying the key social, economic, and cultural factors, as well as how to address them to affect soil carbon outcomes, may be an important step in achieving changes to soil carbon overall. Participants who had worked closely with farmers affirmed that some farmers do care about changing management practices to increase carbon levels within the soils, whereas management decisions for others are driven by a strategy of maximizing profits while minimizing management. Farmers across this range can be affected by various policy tools and incentives, but these should be designed and implemented carefully if they are to be successful.

When looking at the potential for implementing sweeping changes across cropland operations, a significant fraction of the participants expressed doubts about the likelihood of success, given the complexities of political and social considerations. Several expressed concerns about the already existing policies and their tendency to drive the agricultural sector in the "wrong direction" on a number of fronts. Others felt that a narrowed focus on carbon within soils could further exacerbate this issue. One participant argued that investment and policy should perhaps be targeting soil health overall, which could very likely lead to soil carbon sequestration, but should not be the focus. "Spending money on something when we don't know if it's going to work" should not be the approach, they stated, along with "reframing the way investment is allocated could still result in the desired outcome of soil carbon while also having many other benefits." A political consideration in support of this narrative is that it may be more palatable to conservative stakeholders and policymakers, while having the potential to be "broadly beneficial to farmers and rural communities", without just focusing on carbon. As a concurrent co-benefit, policies aimed at enhancing soil health could have real potential to positively impact carbon sequestration.

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Economic considerations

Overall, participants expressed difficulty in separating economic considerations from other factors. Survey responses noted the importance of economic factors in shaping the adoption of practices that can enhance SOC and cited such factors as an important component of any policies designed to encourage adoption of such practices. However, workshop participants were not able to specify meaningful details about such considerations. For instance, they did not mention particular economic thresholds at which certain practices would be economically viable, nor were they able to successfully link various levels of carbon prices to the potential delivery of specific volumes of soil carbon sequestration. The Project Team interprets these outcomes as signifying an absence of expertise among this group. They recognized the importance of such considerations and seemed open to accepting credible analyses of these issues, but they lacked the particular expertise to go deeply into these issues themselves.

We note that a range of analytical approaches are utilized by economists to address such questions, ranging from basic econometrics to more sophisticated spatially explicit approaches. However, we are not currently aware of a comprehensive and widely accepted study that addresses the relationships between economic factors (including carbon price), the adoption of carbon sequestering practices in US croplands, and the quantity of soil carbon that could be sequestered. Such a study could yield a marginal abatement cost (MAC) curve (i.e. a supply curve for soil carbon). This may be a topic worth exploring in future research.

Considerations related to carbon markets

This section covers workshop discussions related to carbon markets. Key themes that emerged from these discussions were:

- the need to politically and socially define a target for climate mitigation;
- the potential for coupling field measurement with remote sensing,[1] proxy measurements, and modeling technologies to improve cost-effectiveness and accuracy of carbon estimation;
- the need for making data publicly available;

[1] While only a few participants were experts in remote sensing techniques, the topic may be worthy of deeper exploration. New remote sensing products or data analysis approaches have the potential to be utilized in ways that could answer key questions related to GHG flux processes in agricultural landscapes. For example, some GHGs are produced during ephemeral conditions that relate to the timing of certain factors in the field, such as the length of time a field is saturated with water. Imagery collected with high spatial and temporal resolution can now provide precise information about the extent and duration of these conditions, in a way that was not possible in previous generations of remote sensing. Other applications that relate to the use of active remote sensing or hyperspectral data may also be relevant.

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- the risks of public discourse fixating on carbon rather than greenhouse gases;
- whether an offset model provides appropriate incentives for soil carbon sequestration;
- the risks of relying on limited types of management practices as opposed to a portfolio approach; and
- concerns over 'net zero' greenwashing, to the extent that corporations are relying on soil carbon credits.

An overarching consideration was the need to define–politically and socially–what is meant by climate mitigation. In order to understand whether emissions reductions are truly occurring beyond a ton-by-ton market-based accounting system, there must be an agreement on the minimum number or target that society is aiming to achieve.

In terms of measurement, there is growing emphasis on using remote sensing proxy measurements. Some entities, particularly in the private sector, indicate to decision-makers that there is no need for additional measurements because remote sensing provides comprehensive data. The scientific community knows this is not the case. Remote sensing is valuable but it must be coupled with on-the-ground measurements on activities that affect soil carbon sequestration (e.g., digging). Similarly, when it comes to large-scale projects applying a set of management practices and heavily relying on robust modeling frameworks, then ground measurements are necessary for a market context, but do not need to be widespread to validate the modeling data.

This two-pronged approach to measuring soil carbon would be feasible if data were made public, allowing scientists to better understand the relationships between remote sensing data and on-the-ground measurements. Currently, much of this data is privatized and monetized which is beneficial for some private sector entities but fails to provide societal benefits–building collective understanding of the climate mitigation potential of soil carbon sequestration on croplands. This understanding would help inform public decision-making and investments in soil carbon sequestration, in addition to the carbon markets.

The emphasis within public discourse and market mechanisms is on carbon, though from a scientific climate mitigation perspective, looking at net greenhouse gas or nitrogen management could yield more significant and easier to define contributions. If the goal is to mitigate climate change, perhaps there is an opportunity to help shift public discourse beyond the narrow focus of (soil) carbon sequestration, to pursue non-reversible emissions reductions. One factor that is not well considered in the offsetting model is that driving changes in soil carbon need to be sustained over time. The notion that a buyer can purchase a one-time credit and walk away from the transaction assuming that sequestration is permanent is very

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challenging for soil carbon. The offsetting model may not be appropriate for the particular type of climate mitigation that soil carbon sequestration provides. Rather, the emphasis may need to be on the delivery and mechanisms for providing incentives over time.

Some participants indicated that it was concerning to see other promising solutions, such as better fertilizer management, multicropping, and demand-side measures being undervalued due to the over-emphasis on soil carbon in the carbon market space and within public discourse. It is important to recognize the potential trade-offs in the types of investments made in incentivizing some practices over others. Too much focus on incentivizing some well-known practices may detract from our ability to recognize and incentivize less conventional or combinations of practices that could yield a greater impact with the same amount of resources. To avoid this, it will be important to prioritize incentives and make them proportional to the anticipated, evidence-based outcome, as opposed to subjectively choosing to incentivize some practices over others.

Others expressed concern about major corporations claiming to be carbon neutral by buying "useless, or very unreliable soil carbon credits" which may look advantageous in the short-term for marketing purposes, but will not make a meaningful contribution to climate mitigation and therefore presents a longer-term societal risk. Further to that point, some participants cautioned that the scientific community needs to be careful about how science is being used for carbon market greenwashing.

Refined Statements

During the course of the last day of the workshop, the participants worked collectively to revise a set of statements developed by the Project Team based upon the discussions throughout the workshop. These revised statements were included in a follow up survey to the entire group of study participants with the aim of gauging the degree to which participants agreed on each statement. These resulting statements were revised via the consideration and implementation of the suggested edits, comments and discussions throughout this session. Although these statements did not garner complete agreement in a second survey, the revised statements yielded much greater agreement than the original statements. In some cases, simple and minor tweaks of the language allowed for much greater convergence amongst the workshop participants.

Prior to the collective work to revise and refine the testable statements, the Project Team presented the following chapeau statement intended to provide context and to convey a collective understanding of these issues:

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There are management options than can increase soil organic carbon, and in many cases, these same practices can also improve the long-run productivity, profitability, and risk profile of the operation. Soil organic carbon is one of several key indicators of soil health, and activities that sequester and/or stabilize soil carbon can contribute to climate mitigation, as long as they do not increase other greenhouse gases.

The revised testable statements are as follows:

- Though increases in soil carbon stocks have been demonstrated in many contexts, soil scientists do not yet have a comprehensive enough understanding of the processes (across all permutations and combinations of management practices and biophysical conditions) to accurately predict the quantity, pace, and durability of soil carbon accumulation and/or sequestration potential in croplands.

- Our understanding of biogeochemical processes that affect soil carbon under cropland management practices could be improved through efforts to expand on existing data, through 1) more robust sampling efforts over more diverse conditions, 2) more coordinated and sophisticated modeling, 3) synthesis with other types of information, such as remote sensing, 4) incorporation of socioeconomic factors that drive practical adoption, and 5) an increase in studies that focus on microbial transformations.

- Efforts to identify the management practices that maximize soil carbon accumulation permanence while also ensuring food security in any particular geography should test such practices under working farm conditions and should include unconventional, hybrid, or even novel management approaches, whenever there is reason to suspect that such approaches have potential.

- Efforts to increase and avoid loss of soil organic carbon in agricultural lands will benefit from a strengthening of information exchange that translates and delivers knowledge between the research community and agricultural stakeholders, including land owners.

- Multiple changes need to occur to maximize soil carbon accumulation in all contexts seeing that changing conditions, such as climate change, call for changing practices;

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achieving the highest potential in any given location is likely to require a tailored and adaptive approach that takes into account the specific biophysical conditions at the location, its management history, and the dynamic climatic and economic conditions anticipated in the future.

- Economic incentives for improving soil health or its components (e.g., soil carbon) could help drive changes in cropland management; however, a singular focus on soil carbon could lead to perverse outcomes and unintended consequences, including an increase in other greenhouse gas emissions.

- Economic incentives intended to drive an increase in soil carbon must be sustained over the long run; otherwise, producers may dis-adopt the practices that accumulated and stabilized soil carbon, risking its release and the reversal of any benefits

- Though we lack the ability to precisely predict the quantity, pace, and durability of soil carbon accumulation in all locations, current science gives us high confidence in predicting spatially aggregate outcomes, when they account for uncertainty. As a result, the highest confidence in outcomes may be a result of economic incentives designed to encourage widespread and durable changes in cropland management practices across landscapes aimed at improving soil health, with conservative quantitative expectations for climate mitigation.

The below statements were also included in the second round survey based upon a recommendation from EDF:

- Managing agricultural soils for improved soil health is low risk and has little downside. ****Note that this was pulled from the chapeau statement in order to gauge the consensus on this aspect*

- Soil carbon does not represent the largest opportunity for climate mitigation in agricultural systems (other pathways involving fertilizer, managing on-farm GHG emissions, etc., have higher potential).

- The climate mitigation potential of agricultural soil carbon is not large enough to warrant major investment.

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- Climate mitigation efforts that prioritize soil carbon while ignoring other aspects (e.g., nitrogen, methane, water) will create unintended consequences for climate and ecosystem health.

Strategic considerations for advocacy

The following section covers the many areas that could be taken into consideration through advocacy efforts gleaned from discussions throughout the workshop.

To begin, the USDA recently announced that they intend to spend $9 million on climate research. This presents the potential for some of those funds to be allocated toward research on management practices that improve soil health and soil carbon.

Additionally, advocacy organizations could play a role as boundary organizations that sit between the scientists and the practitioners. For example, advocacy organizations could push for the USDA to spearhead a major nationwide program of training extension programs throughout the U.S. This would put people out in the field that are not only educated and well versed in the science around soil health and soil carbon, but are also actively engaging with farmers on a regular basis. Those that are engaged in direct outreach to producers tend to be more trusted, but there are currently institutions that are starved for funding and could be providing the training and expertise in order to deliver this information and technical assistance to producers. A current lack of resources from these institutions puts strain on those efforts. As a result, this has created a vacuum where investment in public resources is lacking, and that vacuum is filled by private companies who each have their own particular agenda. Simultaneously, many of the extension agents that are being pulled away from their roles within universities via recruitment to new carbon market companies with the promise of higher salaries. Hence, public investment into this space is greatly needed to bring public sector priorities back into balance with private sector motivations.

Investment is needed into research institutions that are focused on bridging the gap between what is happening within experimental research stations, what occurs in real work farming conditions and the associated economic constraints and considerations. This could be coupled with making data available and usable across public and private sectors to improve soil carbon monitoring. This is an area that could present significant opportunities for investment and research.

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Lastly, efforts to place legal regulations on carbon marketers and their claims is sorely needed. This effort should be paired with a critical evaluation of the role that carbon markets in facilitating adoption.

Potential implications for future research

Throughout the process of this study, the Project Team was able to glean several areas that have potential implications of future research on a number of different fronts. This section is dedicated to laying out those findings, some of which were indicated directly by participants as areas in which future research is needed. Other areas of future research were pulled together by the Project Team based upon what was observed throughout the process of this study. Overall, participants encouraged further research on these topics as a means to illuminate soil carbon potential and feasibility, but most were careful to withhold judgment about whether this research would indicate that the potential was "significant" as a contribution to climate mitigation efforts. The overall opinion was that gathering more information would be worthwhile and potentially important, but that the scale of investment in soil carbon sequestration was a separate issue that would depend on the findings of future research, potential advances in the cost-effectiveness of practices and monitoring, and correlations between the delivery of carbon sequestration and other (unpriced) co-benefits. Many of the participants believed that it would be premature to rely upon soil carbon sequestration as a key strategy for climate mitigation – but they believed it could still be worthwhile for other reasons.

There is currently a very large body of existing literature, both individual studies and meta-analyses, that, according to one participant, seem to suggest that it is time for a comprehensive synthesis analysis by the soil science community on the present state of science about carbon sequestration within croplands under differing management types. During the workshop, this sentiment was strongly reiterated through statements such as "we really need a serious risk analysis of the literature that has mushroomed over the last five to ten years, relative to what some of the statements that were made twenty years ago based on a limited number of studies."

Participants emphasized opportunities to find avenues for operationalizing existing knowledge within the producer community. This could be achieved by bridging the gap between knowledge within the scientific community and practitioners, and should be aimed at aligning both communities' approaches to soil carbon and management practices. Furthermore, translating scientific community knowledge for the farming community at large is an area worthy of attention. Policy levers aimed at producing more independent crop advisors is one example of an intervention that study participants felt was sorely needed.

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Participants called for studies that could quantify the effects of multiple interventions or wholesale shifts in management (e.g., a conversion from conventional to regenerative practices) on soil carbon processes – with an emphasis on research conducted under real-world field conditions. Furthermore, participants suggested that a comprehensive analysis should be pursued that would look closely at how on-farm results and lived practices compare with evidence gathered from field trials in peer-reviewed literature.

Many participants highlighted the importance of further research to explore the dynamics of soil carbon at greater depth and factors that affect the residence time of soil carbon and the duration of benefits, built upon a full lifecycle analysis. Such research would need to take into account that systematic changes are actively occurring due to climate change. This means that findings of past studies may not hold true going into the future when considering these climatic changes.

Additionally, there could be value in a study that aims to address the scientific relationship between soil carbon and other metrics of soil health, and socioeconomic and policy levers that can affect particular outcomes. It may also be helpful to explore whether investment could be more effectively applied by combining multiple aspects of soil health, rather than targeting soil carbon alone.

Future studies that explore the linkages between biophysical outcomes and various socioeconomic issues in different geographies and cropping systems could shed light on policy-relevant factors. Such large-scale studies that span several disciplines may require a substantial investment of time, resources, and expertise.

Comparative studies that look into agricultural management practices as they pertain to carbon vs. soil nitrogen management could not only help to direct where to invest in research, but could also provide a more accurate view on the kind of soil sequestration potential by both soil type *and* time span. This effort could also serve as a potential guidance for behavior and practice changes that could have the most positive impact in terms of climate mitigation.

More robust and comprehensive research into the impact of soil microbiome restoration and its potential for not only soil carbon sequestration but other GHG emissions relating to soils is an area that is in need of further research and investment. In particular, new and innovative research could investigate the potential for management practices that affect the soil microbiome at depth. Soil microbes are a driving force behind many soil transformations, and carbon storage is one output of these transformations. By further understanding their

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mechanistic roles, going beyond treating microbes as a "black box," the scientific community can better understand those microbial driven mechanisms that stabilize and sequester carbon in soils. This will help to better understand the characterization of differing microbial communities and their effects. Long term studies at depth are also a necessary means for understanding this.

Beyond soil carbon research, participants highlighted a need for targeted and well-tailored policy research that can identify the most effective approaches for activating soil carbon potential. This effort should include the social scientists and should be paired with research investments and incentives that provide long-term support for such research. Engaging with the social science community could fill this important gap area and make headway in understanding societal feasibility of soil carbon mitigation – especially engaging with economists and utilizing techniques of economic analysis, as noted previously. These efforts should not only consider what is currently feasible, but also the dynamic and adaptive responses under a changing climate. As one participant stated, researchers should be "discussing the scientific potential on the climatically dictated basis and then we need a really deep analysis of what is decidedly relevant."

Some researchers are aligning themselves behind an existing set of performance-based metrics for assessing directionally correct impact over time at the farm level. However, the existing suite of models show considerable variation in their focus, design, and outputs, making it difficult for policymakers to understand their collective findings and the sensitivity of their results. Streamlining this process to find an answer that is close enough to create a directionally correct answer over time, pairing that with modeling work and sampling with satellite imagery, as well as other sources, might be a more cost effective and efficient means to look at impact over time. Therefore, efforts to rectify and harmonize model analytics – as has been applied to climate modeling – could facilitate a deeper consensus within the scientific community about soil carbon potential and how to achieve it. This understanding can then be embedded into systems for targeting financial mechanisms, such as access to loans or government programs.

While participants noted that many interventions have been called "innovative," no one has taken a comprehensive look at what is actually innovative and what is not, and identifying where there are opportunities for novel contributions within agricultural management practices. Such an effort might help to identify truly promising areas for research, development, and investment.

A study focused on answering what is the scientific relationship between soil carbon and other metrics of soil health is also needed. This study could also aim to answer what socio-economic

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and policy levers need to be pulled in order to lead to a particular outcome? Furthermore, this study should aim to determine where the greatest overlaps lie between technical and feasible sequestration through the implementation of a statistical analysis from a diverse set of soils samples from a wide range of diverse conditions. This should also aim to determine an accurate scale in which to monitor soil carbon stock changes.

Lastly, as carbon markets emerge, beyond regulation and oversight, a critical evaluation of the role of carbon markets in facilitating adoption should be put into action.

Conclusions and Recommendations

Our study set out to explore the degree of consensus among scientific and civil society communities about the potential for soil carbon sequestration in croplands as a climate mitigation strategy. On matters related to the science and understanding of processes that affect soil carbon, the Project Team found relatively high agreement about the following points:

1) scientific understanding of these processes is sufficient to support action, with confidence in the directional effect of the outcomes for soil carbon;
2) scientific understanding is not yet capable of delivering quantitative predictions of outcomes for soil carbon with a level of accuracy and precision that is desired for successful implementation of performance-based policies, including carbon markets;
3) expansion of research to cover under-studied aspects – such as soil carbon dynamics at greater depths, combined effects of multiple interventions over time, and more robust understanding of geographic differences – may have the potential to improve our predictive power to a level required by market-oriented policies;
4) the disciplinary realms of the social sciences, underrepresented in our study, may have important insights about factors affecting the uptake and durability of interventions that could affect real-world soil carbon outcomes.

The language of the “chapeau” statement resonates with these points – we state them more directly here as a guide for future steps.

As a project team, we urge some caution in interpreting the results of this study. As we noted in a few places in this report, we eventually reached the conclusion that some of the topics of this project were really beyond the scope of the expertise of its participants. Our findings about the importance of economic, social, and political factors, as well as the potential role of carbon markets, were really measuring the range of opinions about issues that were outside the

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scholarly expertise of most of the participants. Our project revealed some of the important sources of concern among the participants, and they are all relevant stakeholders in any discussions about policy interventions. However, we believe that other stakeholders have more relevant expertise on these topics, and the Delphi method – designed to elicit and characterize expert views – may yield more insightful results on these matters from a group selected to include more specifically relevant types of expertise. These include economists, civil society, and most significantly, social scientists.

Nevertheless, the Project Team believes there is a basis for further advocacy that has emerged from this project. First, within the soil science community, there appears to be widespread support for an authoritative document or report that sums up the state of the science. To be seen as authoritative, it would need to come from a widely respected scientific body, such as the National Academies. EDF could have a role in helping to establish this process. Most of the participants in this project felt that the scientific understanding of soil carbon processes has been established and documented quite well over the past several years; meanwhile, the understanding outside the scientific community has grown rapidly but unevenly, leading to an unbalanced perception of soil carbon potential and, in some cases, interventions that are not sufficiently supported by science. Many participants felt that such problems could be avoided or corrected with the help of an authoritative report.

Second, many participants emphasized the importance of including viewpoints from farmers and other stakeholders, of dialogues that included both scientists and practitioners, and of a research agenda that looked at real-world situations in which soil carbon interventions would be tested. The sensitivity of real-world practitioners to the economic factors associated with soil carbon interventions was a particular area cited for further investigation. However, many scientists felt that soil carbon dynamics under real field conditions, rather than experimental conditions, had not been studied adequately. This work would undoubtedly reveal new insights and, perhaps more importantly, would enhance the credibility of existing science among farmers.

Third, this project led us to believe that the scientific community feels a wide gulf between themselves and the policymakers who are making decisions that affect soil carbon. The Project Team's impression is that the scientists feel that their collective perspective is being drowned out in policy discussions, both by unsupported exuberance and by counterproductive skepticism. To some degree, the scientific community is sending a mixed message – as highlighted in the final day of the workshop, when debate sharpened between two viewpoints. One side said that we should avoid overinvesting in soil carbon sequestration because the potential was too small to make a significant difference in climate mitigation. The other side

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said that we should invest substantially in practices that enhance soil carbon, in part because they can deliver other co-benefits that are difficult to achieve through other means. We noted that these two statements are not actually in conflict with each other, but they send confusing messages to policymakers. Our aim in the final day of the workshop was to try to rectify these different views in a way that could bring the science community together on common ground, and we had some success. More could be achieved through further efforts. But many of these debates can only be resolved in the context of a concrete policy design process. In the absence of such a process, stakeholders can endlessly debate hypothetical scenarios, continuing to talk past each other without making much progress. To us, this suggests that organizing future dialogues around a concrete policy proposal that is being considered as an EDF advocacy position could yield more productive dialogues, proactive identification of solutions, and tangible outcomes. The research agenda that was developed by the participants in the workshop could be a component of such a policy proposal, but it should probably include a more comprehensive approach that addresses all greenhouse gases, the role of croplands within the broader agriculture industry, the potential for improving the sustainability of cropland agriculture through improvements to soil health, and the potential for incentives to shift practices and improve the livelihoods of farmers.

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Appendix: Research process and survey results

1. *Interview Questions & Script*

Thank you for taking the time to complete this interview. This interview, and subsequent surveys and workshops, are intended to gather diverse perspectives from both the scientific and environmental NGO communities on the potential for soil organic carbon sequestration. This study is focused on croplands that remain croplands, and our primary interest is in US croplands. However, we are also interested in global perspectives, so please do bring any international insight you may have to your responses and participation. We also recognize the many co-benefits of management practices aimed at increasing soil organic carbon, but that is not the focus of this study.

The overall objective of this study is to assess the degree of agreement and/or convergence on the interpretation of the science for croplands soil organic carbon. Furthermore, in areas where we find a lack of convergence, we aim to identify a set of research questions that may help guide convergence in the future.

Your participation is voluntary, of course, and you as a respondent have the right to determine if you will remain anonymous or choose to be identified to our client, Environmental Defense Fund. In either case, the only individuals who will have access to information identifying you will be the members of the Project Team administering interviews and surveys: Jennifer Brown, Jason Funk, and Kristy Buckley. The Project Team will utilize this identifying information in order to track the progress and shifts in key perspectives over the course of time. You may be invited to participate in additional surveys and/or interviews as the project progresses. The data collected will be shared with the team overseeing this project at the Environmental Defense Fund, and in subsequent deliverables and reports, but all identifying information will be stripped for those that choose to remain anonymous.

1. Please state your name, institution, title, geographic location, and some explanation on your work around soil carbon and other greenhouse gas sequestration. (For record keeping purposes for the Project Team).
Answer:

2. Please describe your views on the feasibility of meaningful climate change mitigation through soil organic carbon sequestration in US cropland agriculture. Meaningful feasibility is defined as soil organic carbon sequestration that is actually achievable at the technical level, while also taking into consideration the economic, social, policy, and geographic constraints.
Answer:

a. **To what extent do you see a strong scientific consensus on the feasibility of climate change mitigation through soil organic carbon sequestration on US cropland agriculture?**
   Answer:

b. **If there is not scientific consensus, what, in your view, needs to be further explored to arrive at a collective scientific conclusion?**
   Answer:

c. **How did you come to that view or conclusion?**
   Answer:

3. Are there any geographies, practices, or instances for which it is NOT settled?
Answer:

4. What key factors, if any, that you think are most important for affecting the quantity of long-term soil carbon storage in a US cropland agriculture operation?
Answer:

5. How would you describe the broader landscape of scientific and civil society views on the feasibility of soil organic carbon sequestration on US croplands? (e.g., diversity of views, we don't know enough yet, strong convergence)

Answer:

a. **To what extent are economic and social factors hindering the potential for increased soil carbon sequestration among croplands? Which of these factors are in need of more focused consideration when analyzing the potential of soil carbon sequestration in realizable terms?**

Answer:

6. To the extent you are familiar with various soil organic carbon sequestration Measurement, Reporting and Verification (MRV) Protocols[1]? Are there certain measures you favor, and if so, why?

Answer:

a) To what extent do you see major discrepancies among the various MRV Protocols? How would these affect the ability to accurately assess SOC across farmlands?

Answer:

[1] CAR Soil Enrichment Protocol (CAR SEP); Verra Methodology for Improved Agricultural Land (VM0042); Verra Soil Carbon Quantification Methodology (VM0021); Verra Adoption of Sustainable Land Management (VM0017); Gold Standard Soil Organic Carbon Framework Methodology (GS-SOC); Australian Carbon Credits (Carbon Farming Initiative- Measurement of Soil Carbon Sequestration in Agricultural Systems) Methodology Determination (AUS-SM); Australian Carbon Credits (Carbon Farming Initiative-Estimating Sequestration of Carbon Using Default Values) Methodology Determination (AUS-DV); Food and Agriculture Organization GSOC MRV Protocol (FAO GSOC); Alberta Quantification Protocol for Conservation Cropping (Alberta CC); Regen Network Methodology for GHG and Co-Benefits in Grazing Systems and BCarbon Soil Carbon Credit Systems.
These protocols take different approaches to quantifying SOC and net GHG removals. Some use soil sampling only, some combine sampling with process-based modeling, and others use only modeling and remote sensing.

b) To what extent do these discrepancies, if any, play a factor in how you view the potential for SOC in croplands?

Answer:

7. To what extent, if any, has the portrayal of cropland soil organic carbon sequestration in the media influenced scientific consensus about its potential in climate mitigation?

Answer:

8. We are developing a survey to test the degree of consensus on a set of scientific and socioeconomic statements about the feasibility of soil organic carbon sequestration on US croplands. For example: "*More concrete data is needed to accurately identify what improved management practices are needed to generate positive impacts.*" What other statements do you think would be valuable to test in the survey? Why?

Answer:

9. Supplemental: are there any other people you would recommend that we talk to about these issues?

2. Survey Questions - Survey #1

ICRLP & EDF Soil Carbon Sequestration Potential: Assessing Convergence

- **Please indicate your primary affiliation *Select only one**
  - Research/Academia
  - Civil society/NGO
  - Governmental agency
  - Independent consultant
  - Other:
  -
- **Please list the geographic area(s) of your expertise in relation to soil carbon**

- **Please indicate the primary geographic area for which you will provide answers in this survey. *For specific questions that relate to geographic factors, you will have an opportunity to specify the particular geographies to which your answer applies.**

- **In order to help us understand each respondent's perspective and interests, we kindly ask you to indicate whether you or a close family member have a financial interest in the success of a future soil carbon market (noting that your responses are recorded anonymously and held confidentially).**
  - Yes or No

- **Indicate your level of agreement with the below statement*Select only one**
  - *"There is high biophysical and technical potential for climate mitigation through soil carbon sequestration in cropland agriculture."*
    - *Strongly agree, Somewhat agree, Neither agree nor disagree, Somewhat disagree, Strongly disagree*

- **For the following questions indicate what you believe to be the level of technical potential *Select only one**
  - *"What fraction of the technical potential do you believe is ECONOMICALLY achievable within 10 years?"*
  - *"What fraction of the technical potential do you believe is POLITICALLY/SOCIALLY achievable within 10 years?"*
    - *Almost all, A large majority, About half, A small minority, None, I don't know or I prefer not to speculate*

- **If applicable, please indicate the geographic context for your answers for the previous two questions.**

- **How could specific economic, political, and/or social factors be altered to enhance the ability to realize more of the technical potential? Please indicate the geographic context for your answer.**

- **Please describe any other constraints on the feasibility of soil carbon sequestration from croplands and its ability to meaningfully contribute to climate change mitigation that weren't covered by previous questions. Please indicate the geographic context for your answer.**

- **Please indicate the degree of importance on the following operational factors in affecting the quantity of long-term soil carbon storage in a cropland agriculture operation [1=lowest; 5=highest importance]*Indicate your answers in the boxes below - select only one ranking per factor**
  - *Soil texture, Tillage practice, Cover crop cultivation, Cover crop cultivation, Average annual rainfall, Crop history*

- **Please indicate the degree of importance on the following external factors in affecting the quantity of long-term soil carbon storage in a cropland agriculture operation [1=lowest; 5=highest importance]*Indicate your answers in the boxes below - select only one ranking per factor**
  - *Regulatory approaches and frameworks, Accessibility to inputs, Land tenure (i.e. owned vs. short-term leasing), Another factor (not listed)*

- **Which approach, or combination of approaches, have the highest potential to increase long-term soil carbon storage in a cropland agriculture operation? *Select one option below**
    - *Conversion to perennial crops, rsion from conventional till to no-till, Cover crops/ strip cropping, Riparian restoration beyond the edge off the field, All of the above, Another approach (not listed), A specific combination of approaches (specify here)*

- **Please indicate the following factors in the order to which each one contributes to the degree of uncertainty in quantifying high-quality carbon credits. [1=lowest; 5=highest importance]*Indicate your answers in the boxes below - select only one ranking per factor**
    - Measurement of change in SOC (reliance on sampling vs models, depth of sampling scale of sampling needs, etc.)
    - Comparability of credits derived from different protocols
    - Applicability of methodology across all relevant geographies and crops
    - Accounting for permanence, leakage, additionality, uncertainty, reversals and risk
    - Accounting for net GHG mitigation (i.e., quantifying changes in N2O, CH4, and other CO2 emissions alongside assessment of carbon sequestered)
    - Accounting at scale (e.g., regional oversight or aggregated projects) that provide accurate estimates of net sequestration
    - Measurement of change in SOC (reliance on sampling vs models, depth of sampling, scale of sampling needs, etc.)
    - Applicability of methodology across all relevant geographies and crops
    - Accounting for net GHG mitigation (i.e., quantifying changes in N2O, CH4, and other CO2 emissions alongside assessment of carbon sequestered)
    - Accounting for permanence, leakage, additionality, uncertainty, reversals and risk
    - Accounting at scale (e.g., regional oversight or aggregated projects) that provide accurate estimates of net sequestration
    - Comparability of credits derived from different protocols

- **Are there any other important criteria you would include that are not mentioned above?**

- **Overall, do you think the relevant science is mature enough to support a market for tradable credits derived from cropland soil carbon? If not, what areas of science would need to be improved?**

- **Please rate your level of agreement with each of the following statements*Select only one** *Strongly agree, Somewhat agree, Neither agree nor disagree, Somewhat disagree, Strongly disagree*

- A clear and widespread understanding of the potential to increase SOC through farming practices will require substantial bolstering of the existing data on spatial and temporal patterns of SOC for working farms under various management practices
- Achieving the full technical potential for SOC on croplands would require implementation of practices (or combinations of practices) that are currently rare and/or are not economically viable for most farming operations
- Agricultural management practices have the potential to significantly increase additional SOC and maintain the increased stock over long time-frames, even if we take into account the possibility of leakage and reversal
- For most areas, currently available data are insufficient to accurately quantify the effects of changes in management practices on soil carbon sequestration
- The SOC potential for farmlands across the range of spatial and temporal variability could be accurately quantified if we carefully applied more rigorous approaches to existing data
- The SOC potential for farmlands across the range of spatial and temporal variability could be accurately quantified if we carefully applied more rigorous approaches to existing data
- Soil sampling is essential as the basis for setting baselines and determining the level of certainty in measuring SOC impacts of farming practices across the range of spatial and temporal variability
- The potential for increasing SOC only occurs in a relatively limited set of geographies or a limited set of biophysical conditions
- The best means of establishing agreement about the potential for soil organic carbon sequestration within agricultural croplands would be a large-scale synthesis study of biophysical, land-use, and socio-economic data conducted by recognized scientific experts
- Promoting soil carbon sequestration for soil health has multiple social, economic, and climatic co-benefits
- Promoting soil carbon sequestration as a major climate mitigation strategy poses significant risk, considering the uncertainties about long-term sequestration potential

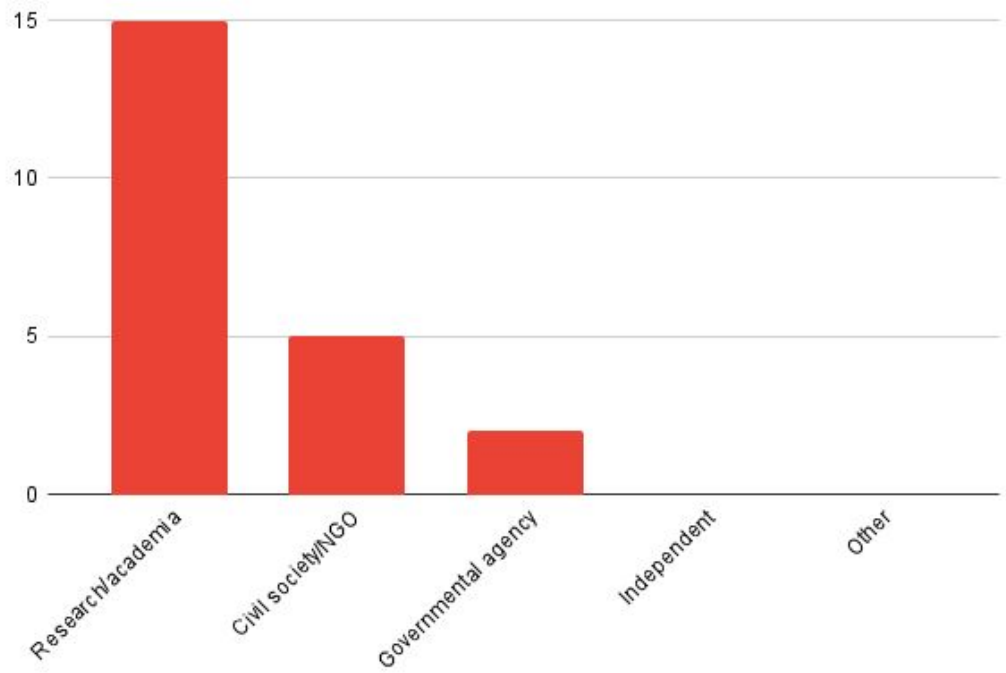
- **Please state which source(s) of information you believe are most trusted by members of each of the following categories, with regard to establishing the science about long-term soil carbon storage in a cropland agriculture operation.**
  - You as an individual
  - Scientists

- Influential Advocacy Organizations
- Farmers
- Somewhat not aligned

- **From your perspective, how aligned are your personal views with the core views of the scientific community?**
  - Extremely aligned
  - Somewhat aligned
  - Neutral
  - Somewhat not aligned
  - Not aligned at all

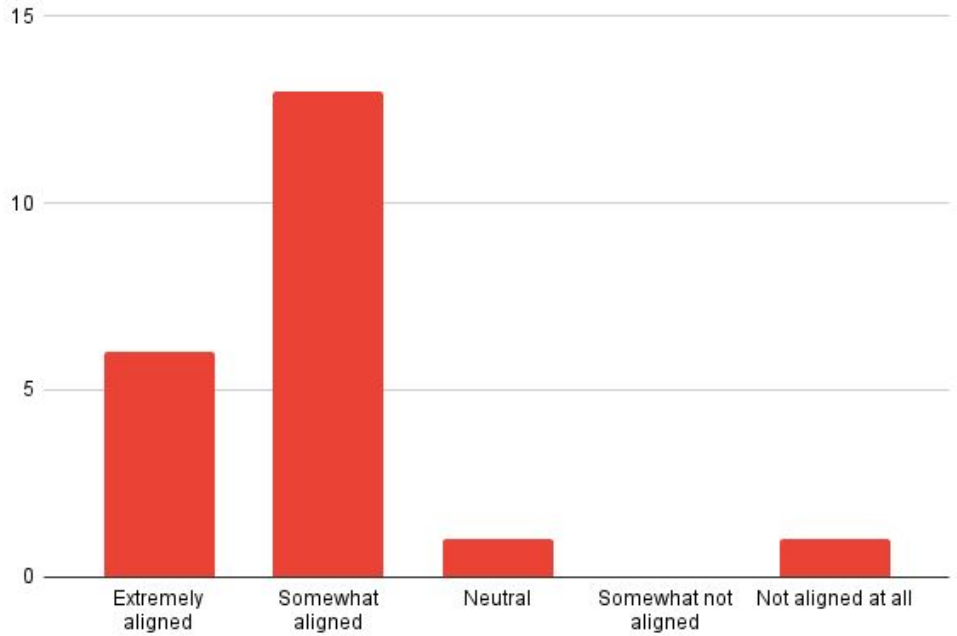
Survey results

Please indicate your primary affiliation



68% research/ academia

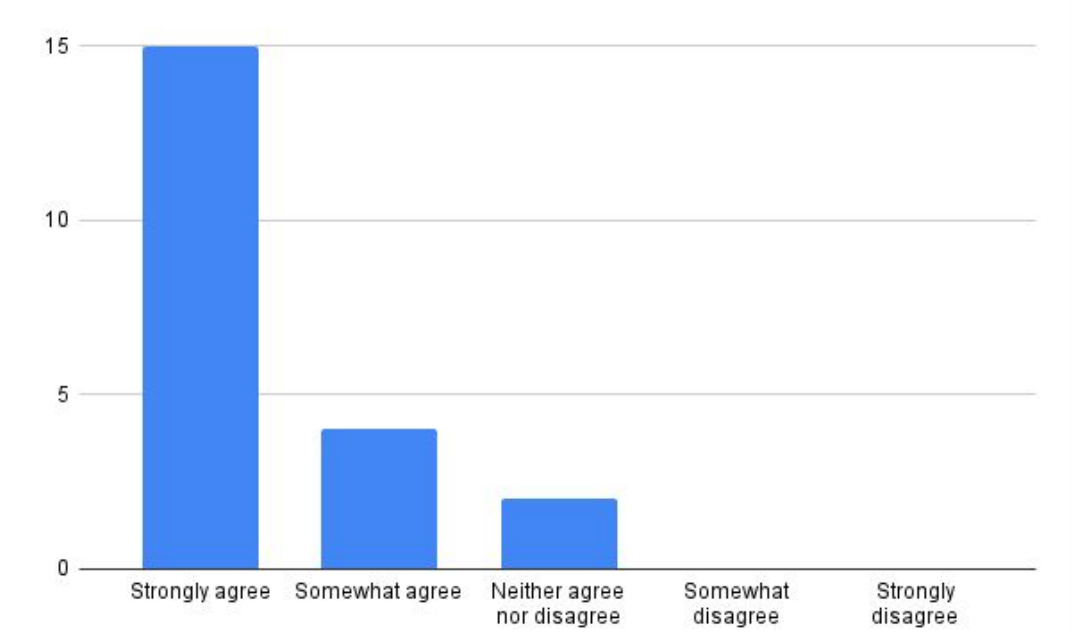
From your perspective, how aligned are your personal views with the core views of the scientific community?



90% aligned

5% not aligned

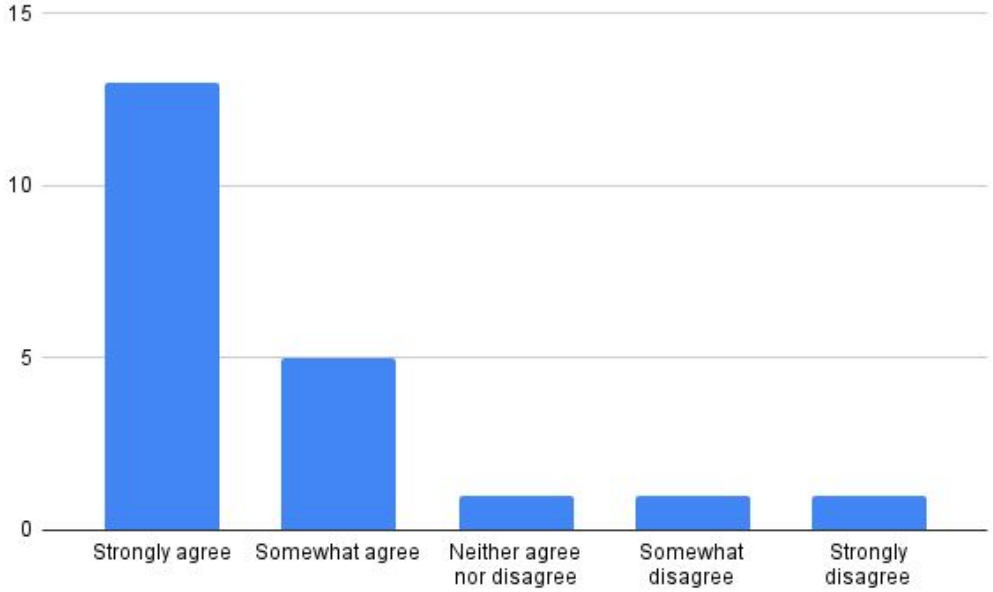
Promoting soil carbon sequestration for soil health has multiple social, economic, and climatic co-benefits.



90% agree

0% disagree

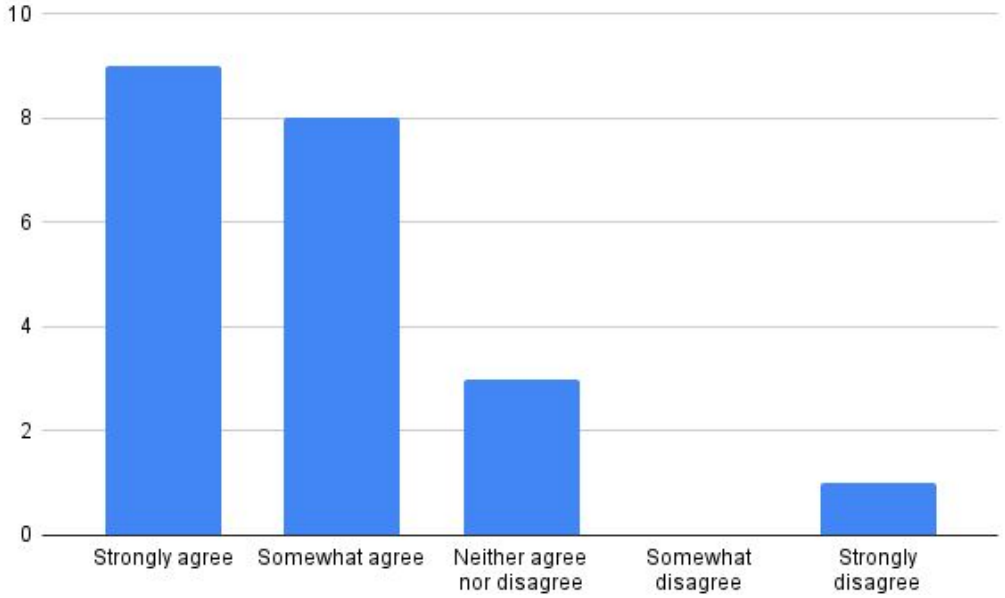
Soil sampling is essential as the basis for setting baselines and determining the level of certainty in measuring SOC impacts of farming practices across the range of spatial and temporal variability.



86% agree

10% disagree

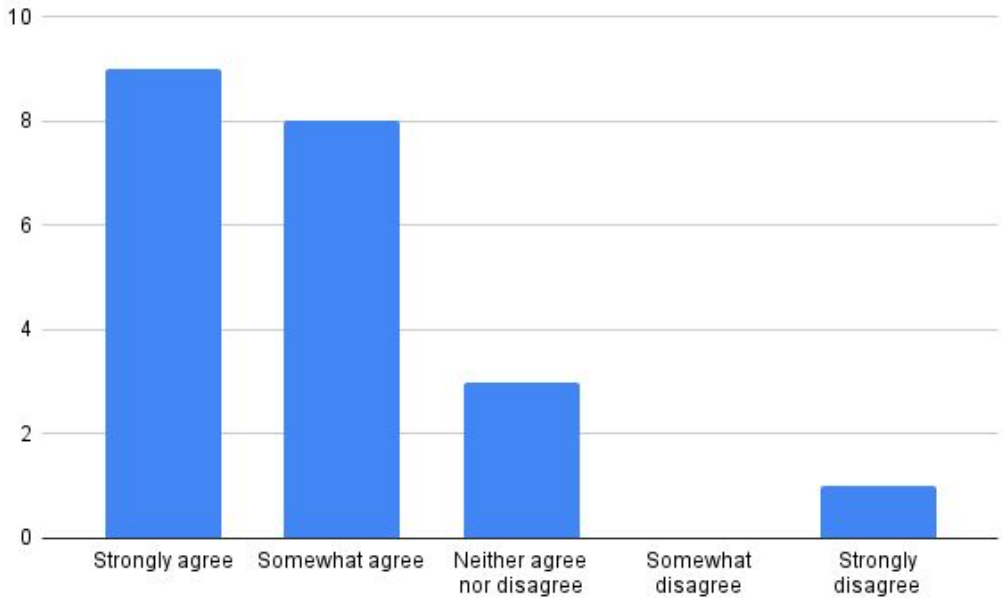
A clear and widespread understanding of the potential to increase SOC through farming practices will require substantial bolstering of the existing data on spatial and temporal patterns of SOC for working farms under various management practices.



81% agree

5% disagree

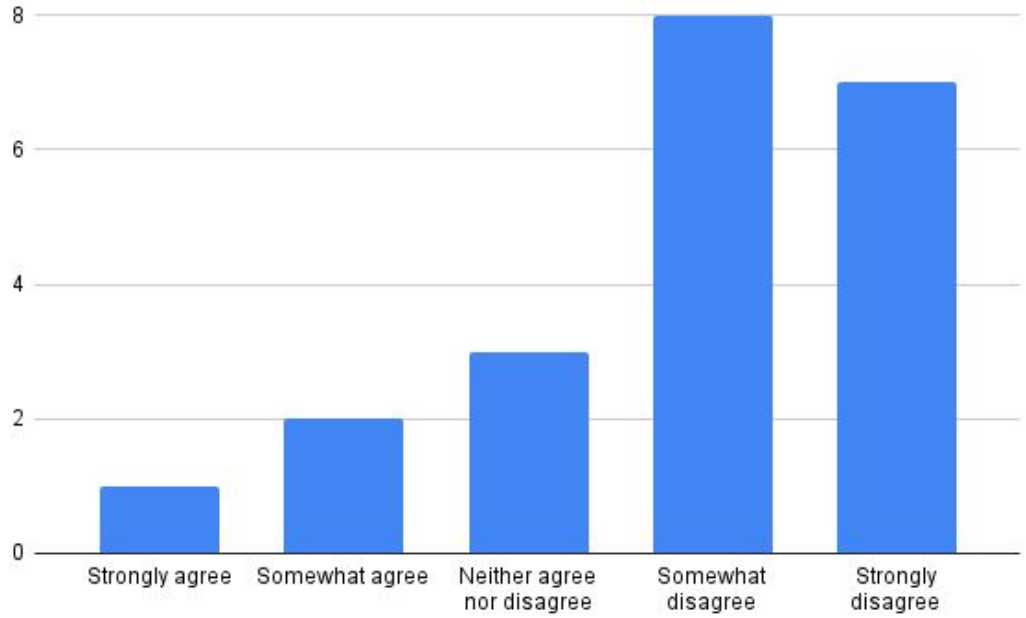
Agricultural management practices have the potential to significantly increase additional SOC and maintain the increased stock over long time-frames, even if we take into account the possibility of leakage and reversal.



76% agree

14% disagree

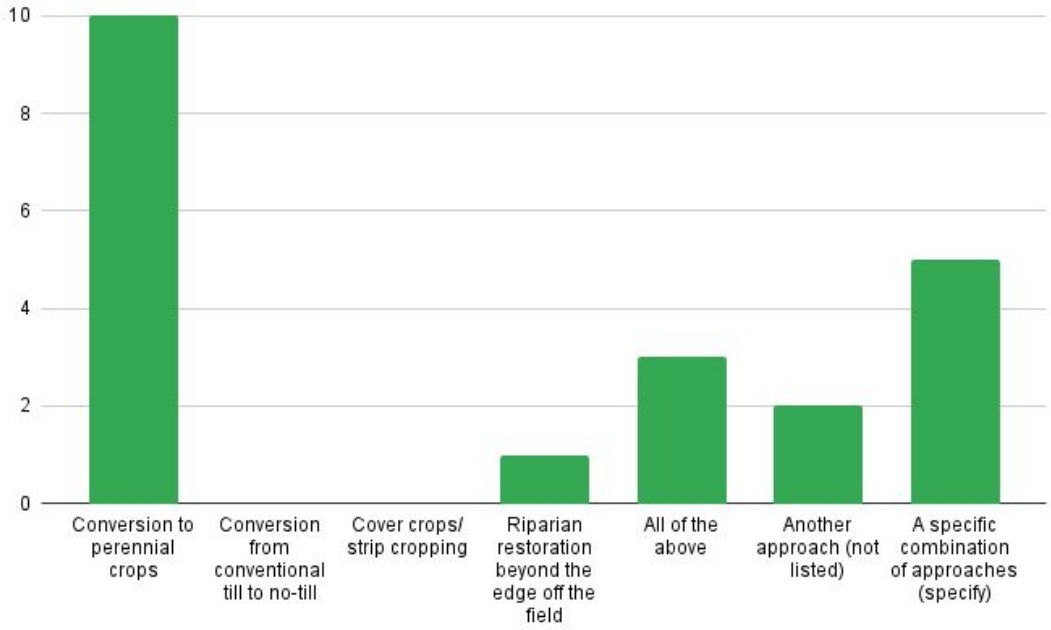
The potential for increasing SOC only occurs in a relatively limited set of geographies or a limited set of biophysical conditions.



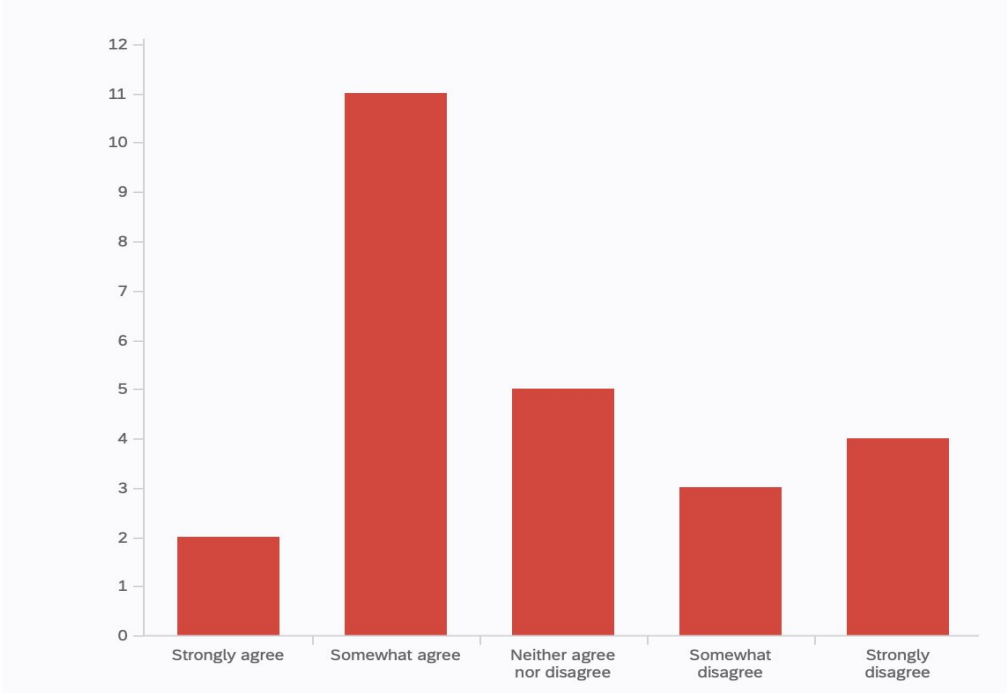
14% agree

71% disagree

Which approach, or combination of approaches, have the highest potential to increase long-term soil carbon storage in a cropland agriculture operation?



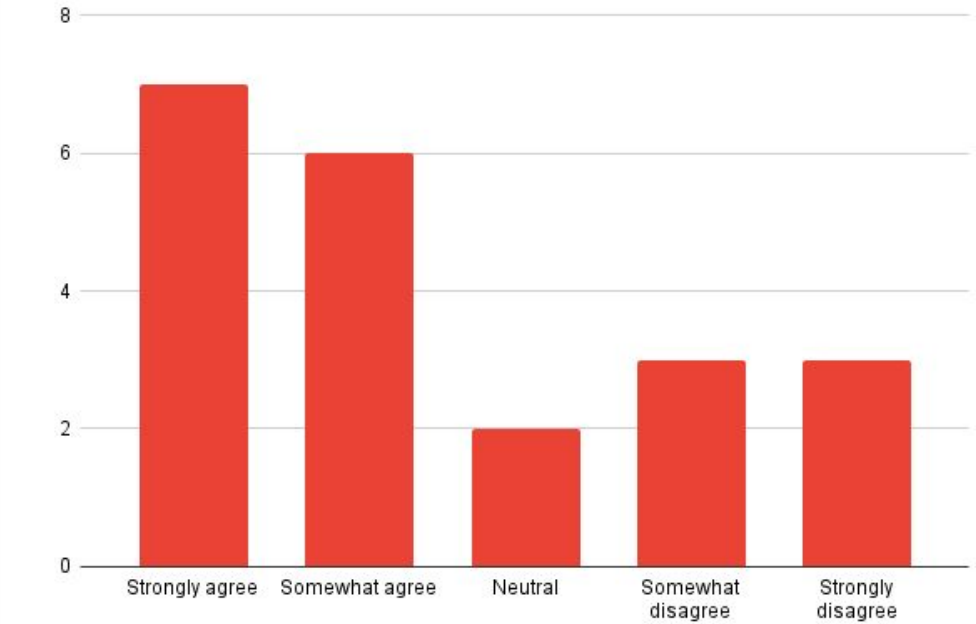
The best means of establishing agreement about the potential for soil organic carbon sequestration within agricultural croplands would be a large-scale synthesis study of biophysical, land-use, and socio-economic data conducted by recognized scientific experts.



52% agree

28% disagree

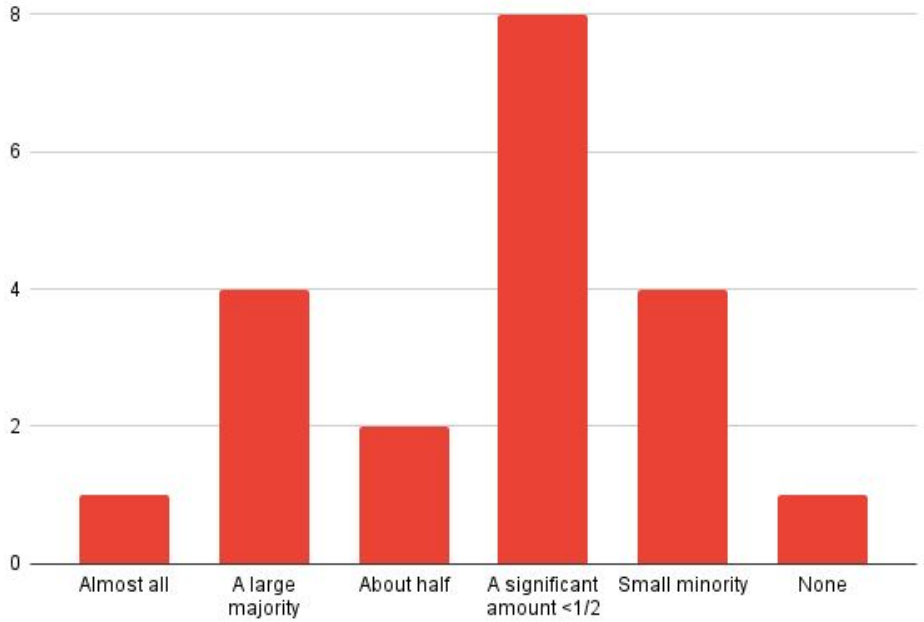
There is high biophysical and technical potential for climate mitigation through soil carbon sequestration in cropland agriculture.



62% agree

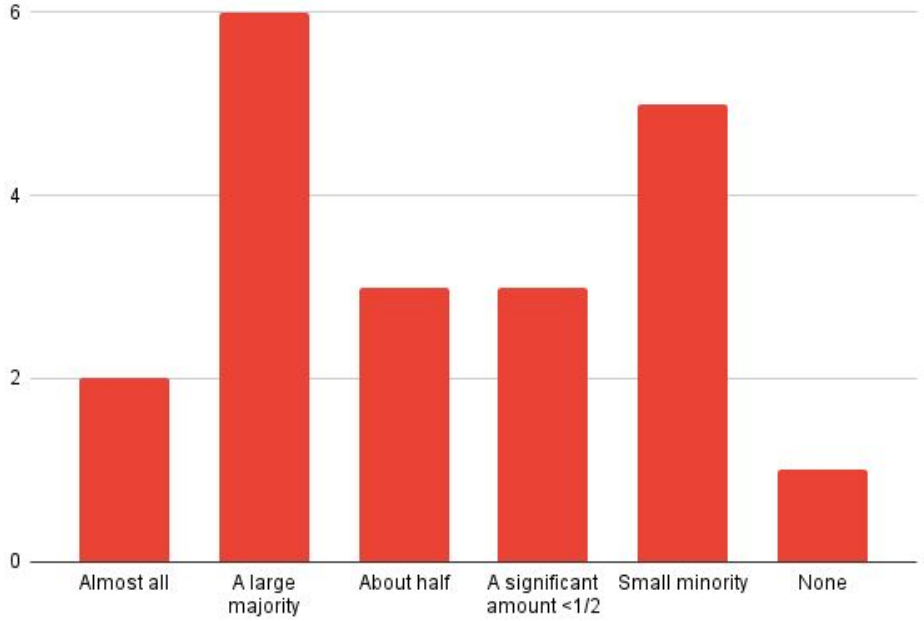
29% disagree

What fraction of the technical potential do you believe is POLITICALLY/SOCIALLY achievable within 10 years?



62% say less than half

What fraction of the technical potential do you believe is ECONOMICALLY achievable within 10 years?



40% more than 1/2

45% less than 1/2

How could specific economic, political, and/or social factors be altered to enhance the ability to realize more of the technical potential?

A combination of barrier removal … marketing … and incentives

Reform banking and crop insurance protocols to allow alternative farming methods to be accepted and implemented

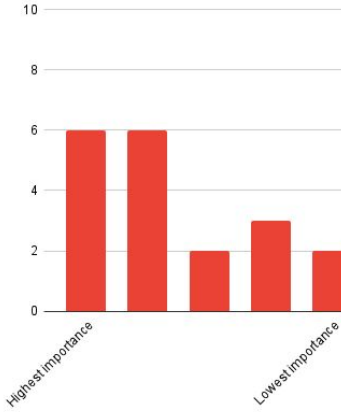
Payments for carbon storage

Major re-education of farmers across the central US

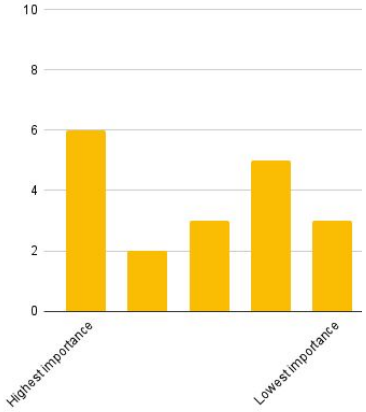
- more support for farmers to adopt improved practices
- continued research that is regionally tailored …
- proactively addressing obstacles
- ensuring that new supports/research address … uncertainties
- prioritize practices/systems that help with climate change adaptation and other environmental and social challenges

Please indicate the degree of importance on operational factors affecting quantity of long-term soil carbon storage in cropland agriculture operation

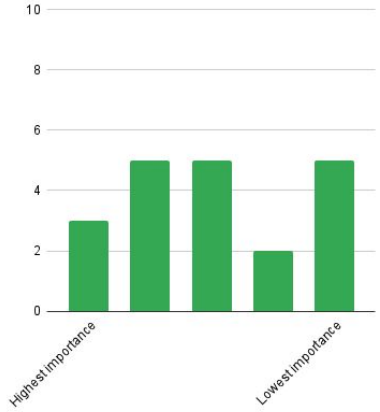
Soil texture



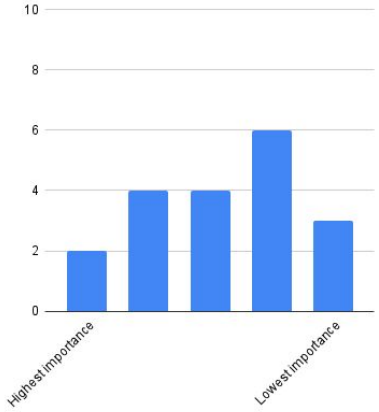
Tillage practice



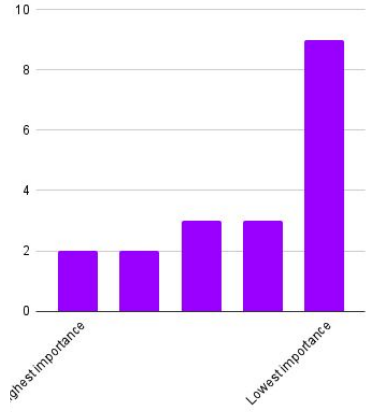
Yearly rainfall



Cover crops

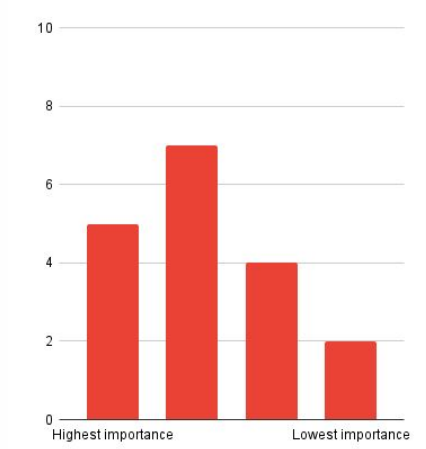


Crop history

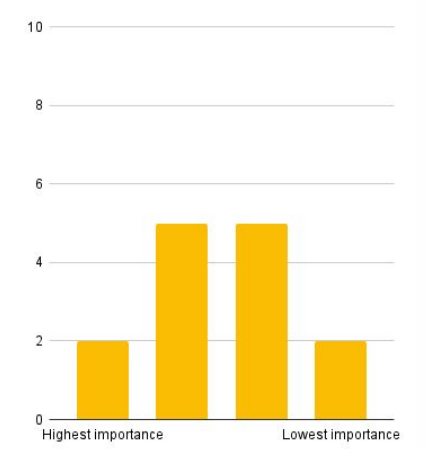


Please indicate the degree of importance on external factors affecting quantity of long-term soil carbon storage in cropland agriculture operation

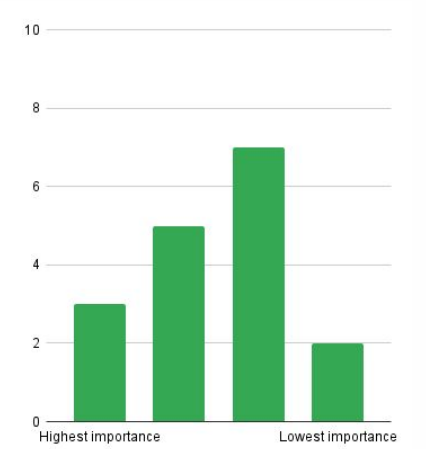
Access to inputs



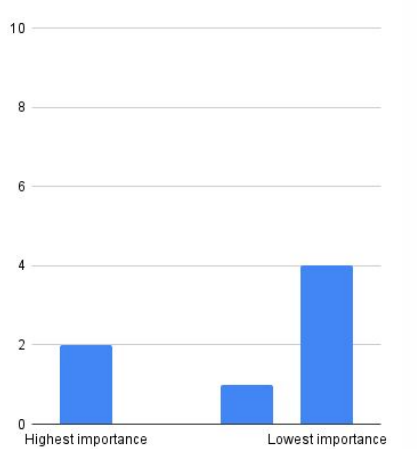
Regulatory



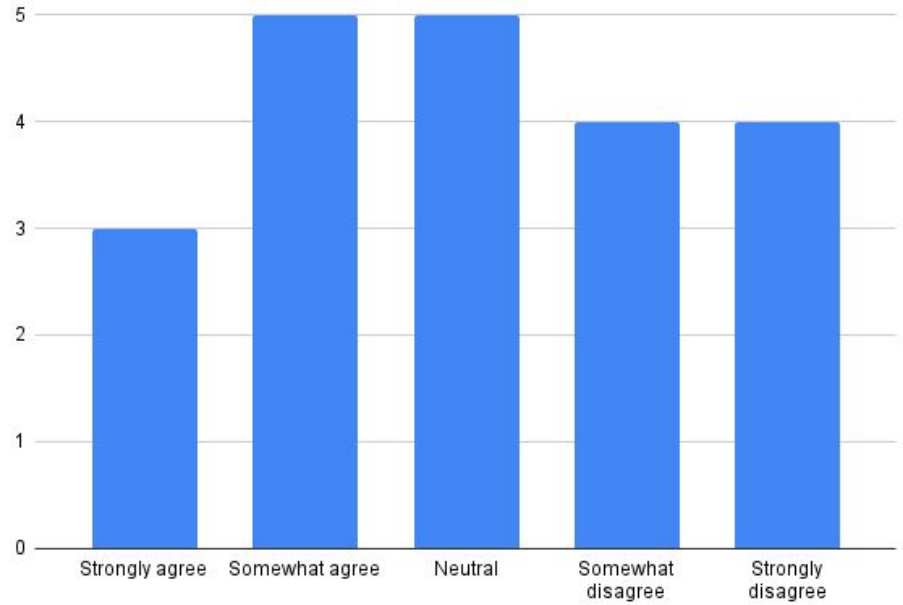
Land tenure



Another factor



Promoting soil carbon sequestration as a major climate mitigation strategy poses significant risk, considering the uncertainties about long-term sequestration potential.



38% agree

38% disagree