State of the Science
Cropland Soil Carbon Sequestration

NATURAL CLIMATE SOLUTIONS
Acknowledgements

This report was supported through a gift to Environmental Defense Fund from the the Bezos Earth Fund and Arcadia, a charitable fund of Lisbet Rausing and Peter Baldwin.

We would like to thank the individuals from each organization who took the time to provide feedback and clarification on our interpretation of their protocols: Steve Wood at The Nature Conservancy; Jonathan Sanderman at Woodwell Climate Research Center; William Schlesinger Arcadia, a charitable fund of Lisbet Rausing and Peter Baldwin Ann Bartuska at Resources for the Future; Keith Paustian at Colorado State University; Peter Woodbury at Cornell University; Dave Wear at Resources for the Future; Ethan Blaire at The Nature Conservancy; Charlie Canham at Cary Institute for Ecosystem Studies.
## Contents

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acknowledgments</td>
<td>2</td>
</tr>
<tr>
<td>Executive Summary</td>
<td>4</td>
</tr>
<tr>
<td>Introduction</td>
<td>5</td>
</tr>
<tr>
<td>Cropland soil carbon status</td>
<td>7</td>
</tr>
<tr>
<td>Conclusions</td>
<td>16</td>
</tr>
<tr>
<td>References</td>
<td>17</td>
</tr>
</tbody>
</table>
Natural climate solutions (NCS) aim to avoid greenhouse gas (GHG) emissions and increase long-term carbon storage in vegetation, soils, sediments, and deep ocean water by conserving, restoring and improving the management of ecosystems. Understanding the potential contributions of these approaches as well as risks and uncertainties is critical for minimizing anthropogenic climate change and ensuring that investments for mitigation achieve intended goals without incurring adverse impacts.

Market interest is running ahead of the foundational and carbon accounting science for many NCS pathways, which adds urgency to the challenge of addressing knowledge gaps. Lack of consensus on what is known and unknown about NCS and the broader array of other carbon dioxide removal (CDR) strategies is a key barrier to progress toward the broad deployment of these strategies.

Multiple pathways for potential net greenhouse gas (GHG) mitigation via NCS exist. This report focuses on carbon sequestration through cropland management. We have obtained review of this summary from scientists and NGO representatives to obtain an initial indication of the current degree of consensus on the state of the science. Thus far we have seen broad agreement on the overall state of the science on measurement and accounting for carbon sequestration. However, some reviewers suggest that EDF is conservative in concluding that market activity should wait for an improved scientific foundation where the directionality of carbon fluxes likely support sequestration. However, EDF’s advocacy for stronger standards for estimating high quality carbon credits is likely supported by all reviewers. We hope that the research we and others will generate by 2025 will refine both our understanding and those standards.
Introduction

The foremost approach to address climate change is to reduce or avoid emissions of greenhouse gases (GHG). However, all scenarios to keep the global temperature increase below 1.5°C (e.g., IPCC 2021) identify carbon dioxide (CO2) removal (CDR) from the atmosphere as also necessary. CDR proposals include but are not limited to land management strategies, enhanced mineral weathering, ocean alkalinization and direct air capture and sequestration. Natural climate solutions (NCS) aim to avoid GHG emissions and sequester CO2 away from the atmosphere in terrestrial soils and vegetation, and sediments and deep ocean water by conserving, restoring and improving the management of ecosystems. Understanding the potential contributions and consequences of these approaches is critical for minimizing climate change and ensuring that investments achieve intended goals.

While NCS approaches appear to have significant potential to help reduce GHG emissions and drawdown atmospheric CO2 concentrations, we see serious gaps in the understanding, analysis and advocacy of potential NCS approaches. For instance, there is no clear scientific consensus on the realizable net carbon sequestration potential of multiple carbon sinks.1 Adding to the challenge of estimating sequestration potential are the difficulties associated with measurement and quantification of net fluxes from these total stocks. For systems like cropland soils we need effective and economical methodologies for measuring and accounting for incremental changes in net carbon sequestered.

Additionally, there is a lack of agreement on how to best address critical accounting elements. These include leakage (whether emissions reductions in one place cause increases in another), additionality (whether reductions would have happened without an incentive program) and permanence (maintenance of carbon stocks over time) at the appropriate scales to ensure that ripple effects of a carbon project in one place do not result in increased GHG emissions elsewhere.

1 In this context we use the term “net carbon sequestration” to denote the amount of new carbon stored minus any other increased GHG emissions resulting from the activity. This phrase is used instead of “net GHG mitigation” to draw attention to the negative emissions or CO2 drawdown that is anticipated, as opposed to reduction of existing emissions.
Social and economic factors also play a critical role in determining mitigation potential. In croplands, socio-economic issues (e.g., land tenure and access to technology, capital, and markets) will determine the rate of adoption by farmers of agricultural practices that store carbon in cropland soils. These factors, especially those beyond the farm scale, must be considered when estimating the realistic SOC sequestration potential of cropland soils, which is likely to be much lower than the estimated maximum biophysical potential.

Despite these challenges and uncertainties, the voluntary market for cropland soil carbon sequestered through agricultural practices has increasing momentum, which adds urgency to the need to address these gaps. Carbon registries and private companies are developing carbon measurement, reporting and verification (MRV) protocols to bring verified carbon credits into the market and to pay farmers and foresters for sequestering carbon.\(^2\) The USDA is considering creating a carbon bank or other mechanism to scale up the adoption of emissions-reducing and carbon-storing agricultural practices.\(^3\) Review of the scientific underpinning of this NCS pathway should help identify the scientific gaps that create risk and uncertainty in carbon credit development.

\(^2\) https://www.edf.org/soilcarbon

\(^3\) A USDA-led carbon bank is broadly defined as a set of policy tools to direct funding to incentivize voluntary climate mitigation. The USDA and Congress are still defining the concept. Read more at https://www.edf.org/ZBJ4.
Cropland soil carbon status

Definition of cropland soils
“Agricultural soils” include a very wide variety of land uses, such as cropland, set-aside and field edges (i.e., the matrix within which cropland exists), pasture, and rangeland. For this report we are focusing on net carbon sequestration in active cropland (i.e., cropland that does not change to another land use or ecosystem type such as forest, grassland or wetland), in order to address the majority of current protocol and market activity. The soil organic carbon (SOC) sequestration potential for cropland restoration to wetlands, riparian buffers, reforestation, and other conversion to perennials is more certain, with fewer challenges for MRV protocols. Pasture and rangeland may require more attention as we move forward.

Broad findings for cropland soils
- Practices that increase the quantity of carbon inputs into the soil by growing plants over a longer time period (i.e., cover crops grown after a season’s cash crop), retaining crop residues or otherwise increasing total above- and below-ground biomass have the potential to enhance SOC stocks. In addition,
- ...practices that decrease soil disturbance can reduce SOC losses.
- The degree to which these agricultural practices increase net carbon sequestration is likely to depend on baseline practice and starting SOC stocks, fertilizer management, and geographic, soil and climatic conditions.
- Soils store a significant amount of organic carbon at depths beyond the immediate tillage zone; however, we lack an understanding of how agricultural management practices impact soil carbon at depth since the majority of soil sampling has focused on the top 30 cm.
- Building soil carbon in agricultural soils has important co-benefits that can lead to improved water quality, reduced erosion, increases in yields, and increased drought resilience through higher soil water holding capacity.
- Understanding the socio-economic factors at regional or societal scales is necessary to understand the realistic mitigation potential of agricultural soil
• ...carbon sequestration; realizing the biophysical potential for carbon sequestration would require practice adoption by 100s of millions of individual farmers across the globe, all with different economic constraints, governance, land tenure, and access to inputs, technology, and markets.
• Calculating the net climate effects of agricultural soil management (and thus carbon credits) requires accurate assessment of CO₂ captured and nitrous oxide (N₂O) and CH₄ released; N₂O will depend on nutrient management and other agricultural practices while non-animal CH₄ (i.e., from rice cultivation) may depend on water management. These GHGs are difficult to compare given that CH₄ is a short-lived climate pollutant with much greater warming potential over shorter timeframes (over 20 years, CH₄ is 84 times more potent than CO₂).
• We lack efficient, scalable and cost-effective soil sampling methodologies to quantify net soil carbon sequestration accurately at the scale of individual fields.
• There is currently little agreement on what constitutes sufficient accuracy for estimating changes in soil carbon.
• We need models that accurately estimate net GHG reductions for crop fields aggregated to a suitable spatial and temporal scale under proposed management interventions for combinations of soils, cropping systems, and climate.
• Models that estimate net GHG impacts must consider how real farms may differ in both practice and outcome from the research sites that are the source of model calibration data (e.g., total biomass produced).
• There is a lack of agreement and serious unresolved challenges in how soil carbon MRV protocols
• ...should account for permanence, reversals, additionality, uncertainty, and leakage.
• There is a risk that the market will move toward protocols and marketplaces that provide the highest number of credits with the lowest overhead verification costs, which might edge protocols with the highest standards and highest quality credits out of the market and result in unreliable credits that do not deliver actual climate benefits.
• There needs to be consistent oversight to ensure environmental integrity in the generation of credits. Such oversight by a public or private entity could set consistent and transparent standards regarding baseline accounting, definitions of additionality, maintenance of sufficient buffers to mitigate against risk of reversal, and leakage accounting to guard against shifts in production.

**Size of existing pool in cropland soils**

The soil science community agrees that the vast majority of agricultural soils have lost SOC compared to their pre-agricultural state. The top 30 cm (~1 foot) of the world’s cropland soils contains approximately 131 Pg of organic carbon (equivalent to 481 Pg CO2e)\(^4\), having lost an estimated 9.6 Pg C (6.8%) from anthropogenic land use changes over the last 12,000 years (Sanderman et al. 2017).\(^5\) In comparison, grasslands and savannas cover a greater total area and contain more than twice the total amount of organic carbon in the top 30 cm (275 Pg C), with estimated SOC losses over the same time period of 5.0% and 3.6%, respectively (Sanderman et al. 2017).\(^7\)

**Practices that can sequester carbon in cropland soils**

It is generally accepted that practices that increase the amount of carbon inputs into the soil by boosting overall plant productivity, retaining residues, and/or keeping plants in the ground can build SOC. By preventing losses of existing SOC, reducing soil disturbance (with less tillage, for example) can also result in greater overall SOC stocks than conventional management. In this way, even if reduced disturbance does not draw down CO\(_2\) to create new SOC, it can provide real GHG emission mitigation. For cropland that remains cropland – and continues to produce a similar mix of commodities – the best options for sequestering new SOC include adding winter or fallow-season cover crops (where moisture and temperature conditions allow) and incorporating perennials into crop rotations. Practices that reduce soil disturbance include no-till (otherwise called direct seeding or direct drilling), strip tillage and conservation tillage. A critical unresolved question is how these practices impact soil carbon stocks at depth. Most research has focused on the top 30 cm of the soil profile, but some studies that have examined carbon dynamics down to 1 m depth have shown that certain practices such as no-till can lead to a re-distribution of soil carbon across the soil profile rather than net accrual (Meurer et al., 2018). On the other hand, soil carbon

---

\(^4\) Note that Pg (petagram) is an SI unit equal to 1 \(\times\) 1012 kg or 1 billion (109) metric tonnes. One Pg carbon (C) is also equal to 1 Gt C, a non-SI unit used in some contexts.

\(^5\) These values combine cropland with cropland and natural vegetation mosaic.

\(^7\) While scientists tend to talk about carbon stocks in terms of the elemental units (i.e., C), the climate change conversation about emissions and mitigation more often refers to CO\(_2\) or CO\(_2\)-equivalents (CO\(_2\)e). One Mg of carbon is contained within 3.67 Mg of CO\(_2\), so these SOC values can be converted from C to CO\(_2\)e by multiplying by 3.67. As this report is oriented toward climate change mitigation, most subsequent mentions of carbon quantities will be in units of CO\(_2\) or CO\(_2\)e.
is much more stable at depth (i.e., it is less vulnerable to decomposition) and so strategies that can increase SOC stocks (e.g., deep rooted crops) below the plow layer are important avenues for further research.

Other opportunities to both store new carbon and reduce SOC losses include agroforestry, restoring wetlands and planting other perennial vegetation at field edges and on marginal cropland. While these strategies have high C sequestration potential per unit area, they fall outside the scope of the current study due to the land use change involved over limited areas if maintaining agricultural productivity and keeping most cropland as cropland. Further, a successful cropland soil carbon program relies on maintaining or increasing productivity within a designated project to provide commodities to meet the demand of global supply chains and to reduce leakage and other risks.

Uncertainty exists in the efficacy of these practices to sequester soil carbon and result in net GHG emission reductions. This uncertainty stems from diversity in climate and soil characteristics, differences in practice (and outcome) between research plots and commercial farms, and high variability in measured SOC and other GHG outcomes. In addition, expectations have been moderated by studies that found no-till reduced crop yield in some regions (Sun et al. 2020) and reduced SOC in deeper soil horizons (Powlson et al. 2014; Du et al. 2017). For all practices, the removal of CO$_2$ into SOC is also time-limited, since SOC tends to approach a new equilibrium level after 20-50 years of change in practice (depending on the type of practice), after which inputs are balanced by losses (Minasny et al. 2017).

Potential magnitude of C sequestration in cropland soils

We found a lack of consensus about the degree to which agricultural soils can be managed to sequester sufficient CO$_2$ to have an appreciable impact in mitigating climate change (VandenBygaart 2016; Schlesinger & Amundson 2019; Bradford et al. 2019). Estimates of the global potential for soil carbon sequestration vary dramatically and are associated with substantial uncertainty (Minasny et al. 2017; Bossio et al. 2020). Estimates of the potential for climate mitigation through increasing the carbon stored in global agricultural soils vary by more than an order of magnitude. For instance, a recently published estimate of CDR potential for cropland soils alone (i.e., excluding grassland) is 6.8 Pg CO$_2$ per year over 20 years (Zomer et al. 2017). The IPCC (2019) assessed the CDR potential for cropland and grassland soils to be between 0.4 and 8.6 Pg CO$_2$ per year. Others have estimated that 1.5 to 8 Pg CO$_2$ per year could be stored in the top 30 cm of agricultural soils over a 20 to 30 year period (Sanderman et al. 2017; NASEM 2019). The high end is more than twice as large as the estimated human-caused soil carbon (down to 30 cm) loss over the last 12,000 years (Sanderman et al. 2017).

Crucially, these are estimates of maximum biophysical potential carbon sequestration. They do not account for the practical challenges of making management changes that sufficiently increase biomass and reduce soil
disturbance at the farm scale. These include finding markets for any new (secondary, cover or rotation) crops; accessing equipment, labor, and sufficient cover crop seed; figuring out seeding and harvest timing to maintain productivity; and getting cover crops or other new species to grow well, all while dealing with uncertain weather. Nor do they account for other socio-economic factors that affect adoption rates of new agricultural practices, such as farmer identity or the realities that even the most sequestration-minded farmers face when considering practice changes, e.g., access to information, social pressures, authority over land contracts, or land ownership issues. For example, depending on the price of carbon alone, Smith et al. (2008) estimated the realizable potential to be between 27% and 72% of the biophysical potential. Sommer and Bossio (2014) suggest that adoption rates of practices likely to increase SOC will limit the global realizable potential to 60% of biophysical potential on croplands. Thus, these types of limiting factors must be considered before we can estimate the realistic magnitude of carbon sequestration in cropland soils.

**Measuring net soil carbon sequestration in cropland soils**

We lack efficient and scalable methodologies to accurately quantify changes in net soil carbon sequestration. SOC can vary significantly over small scales (e.g., cm), and accrues very slowly. The annual change in soil carbon concentration might be 0.01% under realistic implementation of agricultural practices (e.g., cover crops, reduced tillage). Current measurement techniques can detect changes of 0.05%, and the documented average detection from commercial laboratories is 0.1% (Jimenez and Ladha 1993). The inability to detect annual C sequestration in agricultural soils is why MRV protocols that require soil sampling generally stipulate that soil samples be collected every five years. Low precision in the soil C analysis leaves little to no room for any field or analytical error in order to detect a change of 0.05% over five years.

We lack efficient and scalable methodologies to accurately quantify changes in net soil carbon sequestration. SOC can vary significantly over small scales (e.g., cm), and accrues very slowly. The annual change in soil carbon concentration might be 0.01% under realistic implementation of agricultural practices (e.g., cover crops, reduced tillage). Current measurement techniques can detect changes of 0.05% , and the documented average detection from commercial laboratories is 0.1% (Jimenez and Ladha 1993). The inability to detect annual C sequestration in agricultural soils is why MRV protocols that require soil sampling generally stipulate that soil samples be collected every five years. Low precision in the soil C analysis leaves little to no room for any field or analytical error in order to detect a change of 0.05% over five years.

Measurement techniques that allow for greater density of soil samples at a lower analytic cost may improve our ability to detect changes in SOC. One such approach is soil spectroscopy, which can provide accurate measures of SOC at a fraction of the cost of
traditional lab analysis (Paul et al., 2019; Sanderman et al., 2020).

Underscoring the heterogeneity of soils and slow pace of SOC accumulation, research analyzing data from 13 field trials across the U.S. Midwest demonstrated that it can take between 11 and 71 years to detect statistically significant SOC stock changes in agricultural field trials (Necpálová et al. 2014). As a result, it is difficult to detect change at the temporal and spatial scales of interest for GHG reduction programs that credit individual farmers without collecting and analyzing a cost-prohibitive number of soil samples. Soil carbon crediting protocols therefore rely on process-based biogeochemical models and less on field measurements to issue credits in the short term.

Given this reliance on modeled results of annual SOC sequestration, we need models that produce estimates of net SOC sequestration with high confidence — accounting for non-CO2 GHGs—and meet standards of accuracy and uncertainty. Such standards of accuracy and uncertainty are not currently universally agreed upon.

Accounting for non-CO2 GHGs is critical because the emissions of other GHGs may be influenced by the practices adopted for carbon sequestration. For example, if additional fertilizer is applied to improve establishment and productivity of cover crops, emissions of the potent GHG N2O may increase. No-till management is also known to generate increased N2O emissions in certain soil-climate zones because of impacts on soil moisture, especially in the first years after adoption (van Kessel et al. 2013). Evidence suggests that the mitigation potential of no-till systems is only realized when practiced over longer timeframes (Six et al., 2004). Thus, accurate carbon accounting requires that both carbon sequestration gains and other emissions be included. Currently, there is little evidence that existing models can accurately capture net GHG reductions at the field level under all proposed management interventions for all combinations of soils and climate (Tonitto et al. 2018). While the basic soil management practices that are most likely to increase SOC are included in multiple models, validation of these models with high-quality field data is limited to only certain cropping systems and geographic conditions (generally the most common crops and most intensive cropland use).

**MRV protocols**

Addressing uncertainty, permanence, additionality, reversals, and leakage in these heavily managed systems is also complicated. Published MRV protocols address these issues, but with varying thresholds (Table 1). In addition, some protocols do not incorporate trade-offs with non-CO2 GHGs in quantifying SOC credits. These differences mean that credits derived from different protocols are not equivalent (Oldfield et al 2021), precluding application of these credits to nationally determined contributions (NDCs) or emission offsets. Over time, the market may move toward protocols and marketplaces that provide credits with the lowest

---

*Jon Sanderman, Woodwell Climate Research Center, pers. comm. 2021.*
overhead verification costs, which might edge protocols with the highest standards and quality credits out of the market. This potential outcome underscores the need for consistent oversight to ensure environmental integrity in the generation of credits.

Carbon credit accounting
While there has been a growing amount of project development in the agricultural carbon space, no verified credits have been issued to date by any of the major registries: Climate Action Reserve, Verra, and Gold Standard. Indigo Ag, LLC recently announced the first round of payments to 267 farmers with anticipated verification under Climate Action Reserve’s Soil Enrichment Protocol in 2022. Indigo has announced that it has secured buyers for all the credits generated under this project. Other market activity includes the following:

- The Nori Carbon Removal Marketplace has sold 58,813 Nori Removal Tonnes (NRTs, issued for SOC sequestered only, as they do not account for other GHGs) and have 6,276 NRT available for purchase.
- Regen Registry has issued 118,957 credits under their Grasslands Methodology. Microsoft was among the companies that purchased these credits.
- Truterra, LLC’s TruCarbon Program has a contract with Microsoft to develop/deliver 100,000 tonnes.
- The Ecosystem Services Market Consortium (ESMC) has just issued its first round of payments to farmers for ecosystem service credits under a pilot in Kansas in collaboration with General Mills and the Kansas Department of Health and Environment. ESMC has not released their protocol.

Consensus, gaps and disagreements around cropland soil carbon credits
We obtained six external reviews of this summary to highlight points of disagreement and areas that reviewers felt were missing important information. Generally, there was consensus among the reviewers with the main conclusions. Disagreement was raised in response to specific framing of issues (e.g., using variability in ecosystem carbon stocks to illustrate the challenge of detecting change in fluxes of SOC). In these circumstances, we have revised the document to provide more appropriate context to highlight points related to the uncertainty in cropland mitigation potential.

Some of the reviewers also felt the summary’s language around the uncertainty of the agricultural soil carbon sequestration potential belies consensus surrounding the significant potential for climate abatement in agriculture. These reviewers felt that while uncertainty in projections of the magnitude of impact exists, this could result from differences in agricultural systems and interventions considered when estimating projections. Related to this, some reviewers felt that the summary may conflate uncertainty and variability in terms of our understanding of the efficacy of agricultural practices in sequestering carbon. These reviewers agreed that substantial variability exists in the impacts of practices on soil C sequestration (due to different climate and soil types), however, there is a
good degree of certainty on the impact of specific practices within certain systems as well as robust estimates for expected mean outcomes at regional and national scales. All reviewers agreed that there is a large degree of uncertainty about the “practical” and “realistic” potential of using agricultural soils for climate mitigation.

Where reviewers identified important information as missing, we have incorporated key points into the summary. For instance, several reviewers felt that the co-benefits of building SOC on soil health and agricultural resilience and the question of how agricultural practices impact soil carbon stocks at depth should be addressed in greater detail.
### Table 1: Variation in structure and accounting in ten MRV protocols used in the private or public sector (adapted from Oldfield et al. 2021)

<table>
<thead>
<tr>
<th>Issue</th>
<th>Approach</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Measurement</strong></td>
<td>• Sampling.</td>
</tr>
<tr>
<td></td>
<td>• Modeling.</td>
</tr>
<tr>
<td></td>
<td>• Sampling + modeling (hybrid).</td>
</tr>
<tr>
<td></td>
<td>• Sampling + remote sensing.</td>
</tr>
<tr>
<td><strong>Additionality</strong></td>
<td>• New practices are not already implemented on a percentage of land area.</td>
</tr>
<tr>
<td></td>
<td>• Legally required practices are not accepted.</td>
</tr>
<tr>
<td></td>
<td>• Modeling demonstrates carbon storage above business as usual.</td>
</tr>
<tr>
<td></td>
<td>• Practices must be proven to be new and additional to business as usual.</td>
</tr>
<tr>
<td></td>
<td>• There is a reasonable expectation for CO₂ drawdown from project activity.</td>
</tr>
<tr>
<td></td>
<td>• Credits issued for carbon stored after the initiation of soil testing.</td>
</tr>
<tr>
<td></td>
<td>• Credits issued for “look back” periods of 5 to 10 years.</td>
</tr>
<tr>
<td><strong>Reversals</strong></td>
<td>• A percentage of credits are held in a buffer pool to mitigate reversal.</td>
</tr>
<tr>
<td></td>
<td>• The risk of reversal determines whether credits can be sold.</td>
</tr>
<tr>
<td><strong>Permanence</strong></td>
<td>• Depending on the protocol, practices have to be maintained for 10, 20, 25 or 100 years (with buffers held for reversal).</td>
</tr>
<tr>
<td><strong>Net carbon addressed</strong></td>
<td>• N₂O and other emissions are addressed through models/ emissions factors.</td>
</tr>
<tr>
<td></td>
<td>• Emissions are only included if they are &gt;5% of baseline/business as usual.</td>
</tr>
<tr>
<td></td>
<td>• Only SOC sequestered is credited.</td>
</tr>
<tr>
<td><strong>Acceptable uncertainty</strong></td>
<td>• Depending on the protocol, uncertainty cannot be above 10, 15, 20 or variable.</td>
</tr>
<tr>
<td></td>
<td>• The probability of exceedance = 60%.</td>
</tr>
</tbody>
</table>

Information synthesized from ten published and publicly available protocols including 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.
Conclusions

While we were unable to assess the consensus of our summary of the science supporting open ocean blue carbon sequestration, an external review of our summaries of the scientific basis for agricultural soil and temperate forest management carbon sequestration was informative. The experts made two general points: first, the evidence supporting the habitat, biodiversity, water and air quality, drought resilience and other values provided by these systems may be greater than that for carbon sequestration. Rewarding landowners for maintaining those values might be a lower risk than rewarding them for removing carbon. Second, as we had concluded, each of these systems may be able to sequester additional carbon at large scales; however, our understanding of the net GHG mitigation impacts and ability to quantify those impacts is insufficient. Current variation in measurement and accounting methods across registries and protocols undermines the reliability and precision of any credits generated. Standards for measurement, accounting at regional scales, clear approaches for ensuring additionality and permanence, avoiding reversals and leakage, and minimizing uncertainty and risk are all necessary before these NCS pathways can support high quality carbon credits and markets.
References


