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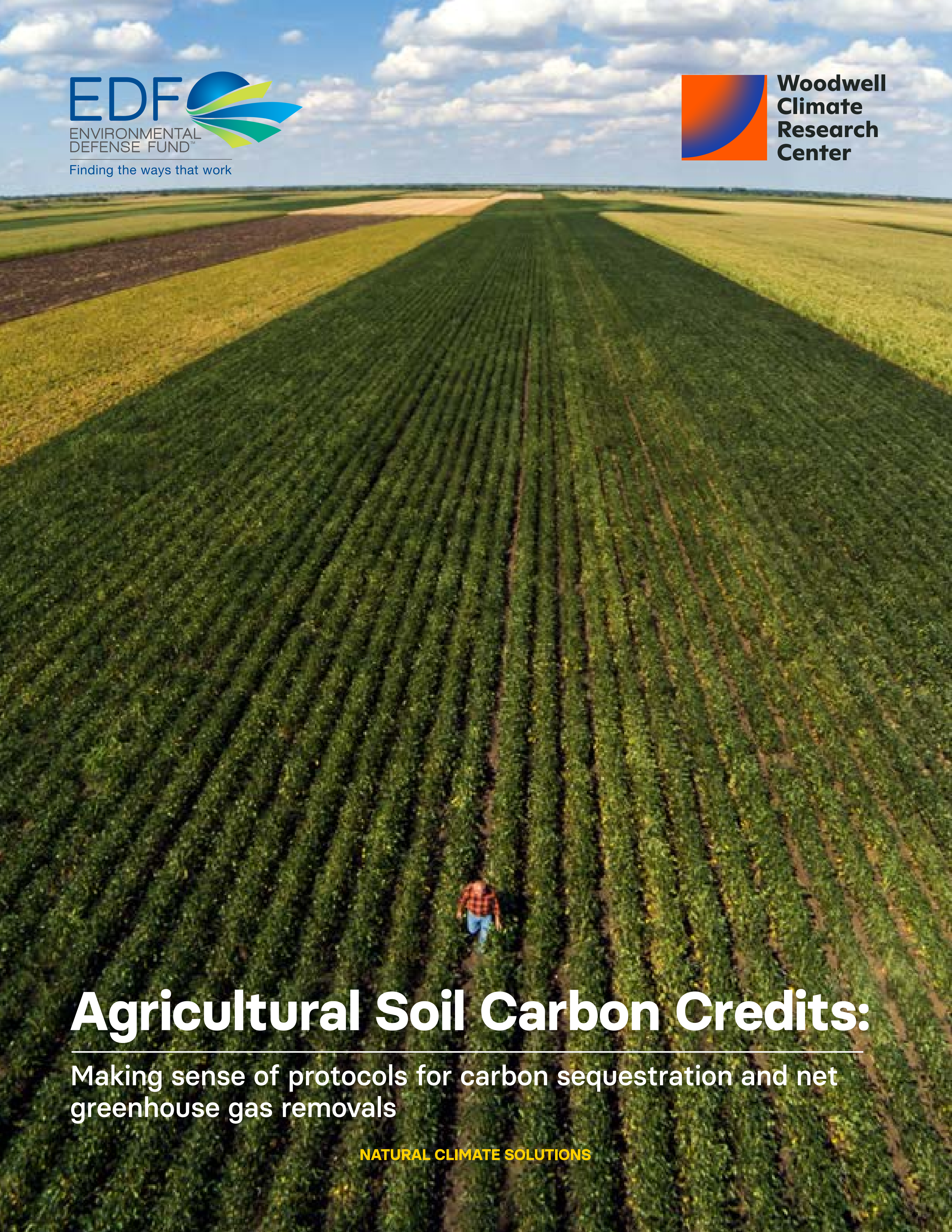

# Agricultural Soil Carbon Credits:

## Making sense of protocols for carbon sequestration and net greenhouse gas removals

NATURAL CLIMATE SOLUTIONS

# About this report

This synthesis is for federal and state policymakers looking to shape public investments in climate mitigation through agricultural soil carbon credits, protocol developers, project developers and aggregators, buyers of credits and others interested in learning about the landscape of soil carbon and net greenhouse gas measurement, reporting and verification protocols. We use the term MRV broadly to encompass the range of quantification activities, structural considerations and requirements intended to ensure the integrity of quantified credits.

This report is based on careful review and synthesis of publicly available soil organic carbon MRV protocols published by nonprofit carbon registries and by private carbon crediting marketplaces.

We contacted each carbon registry and marketplace to ensure that details presented in this report and accompanying appendix are accurate.

This report does not address carbon accounting outside of published protocols meant to generate verified carbon credits.

While not a focus of the report, we remain concerned that any end-use of carbon credits as an offset, without robust local pollution regulations, will perpetuate the historic and ongoing negative impacts of carbon trading on disadvantaged communities and Black, Indigenous and other communities of color. Carbon markets have enormous potential to incentivize and reward climate progress, but markets must be paired with a strong regulatory backing.

## Acknowledgements

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# Contents



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# Executive summary

Agriculture contributes to climate change through direct greenhouse gas emissions and indirect land use change, and it has the potential to help solve climate change through avoided emissions and carbon sequestration, as well as building resilience to unavoidable climate impacts.

The potential for agricultural climate solutions overall has fueled growing investment in credits for soil organic carbon sequestration in particular. The stakes for climate change and farmers are high, and there is a pressing need to evaluate emerging SOC measurement, reporting and verification protocols to ensure they result in high-quality credits that identify real net atmospheric carbon sequestered.

Environmental Defense Fund and the Woodwell Climate Research Center reviewed 12 published MRV protocols for SOC credits generated on cropland and rangeland — eight from the United States, two from Australia, one from Canada and one from the Food and Agriculture Organization. (See Table 1 for additional details.)[2]

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.

Differences in the way protocols and carbon markets estimate SOC and net GHG reductions, as well as the way they account for issues such as permanence and additionality of carbon sequestered, run the risk of creating credits that are not equivalent or even comparable.

This variation makes it difficult to ensure net climate benefits have been achieved. A lack of comparability and standardization will be especially problematic if the U.S. government decides to use SOC credits to meet nationally determined contributions or if sectors required to reduce emissions purchase SOC credits to compensate for emissions elsewhere.

Consistent accounting and verification of direct emission reductions during agricultural production — reduced nitrous oxide emissions via improved nutrient management, reduced carbon dioxide emissions via reduced tractor use and reduced methane emissions from improved manure management — and from avoided land conversion is a less risky and permanent climate solution for supply chain and other public investment. This approach should result in credits that could count toward NDCs or emission offsets.

Improved management practices that aim to build SOC can deliver many co-benefits, including improved water quality, increased yields and yield resilience. Thus, while uncertainty remains about the climate mitigation potential of SOC sequestration, efforts to build SOC are still valuable.

This report:

1. Identifies critical research gaps related to knowledge of SOC accrual in response to agricultural management.
2. Specifies limitations and key uncertainties associated with different SOC quantification approaches.
3. Synthesizes different protocol approaches to issues such as additionality, leakage, reversals and permanence.
4. Outlines critical actions the public and private sectors can collectively take to strengthen the potential for SOC markets.

## Research gaps and the challenges of quantifying SOC

Existing cropland protocols assess carbon sequestered through the adoption of a limited number of practices like cover crops, reduced tillage and crop rotation. Scientists do not, however, have a clear understanding about the degree to which these conservation practices can sequester sufficient atmospheric carbon to have an appreciable impact in mitigating climate change.

This uncertainty stems from a lack of data on spatial and temporal patterns of SOC accrual across working farms and under different management practices. SOC can vary significantly over space, and it changes very slowly over time. This makes it difficult to detect change without collecting and analyzing a high density of soil samples, which is expensive and potentially cost prohibitive. As such, published protocols rely either exclusively on models or on approaches that combine episodic soil sampling, such as every five years, with process-based models.

Confidence that models can produce accurate and unbiased estimates of SOC sequestration is critical, as credits will primarily be issued based on modeled results in the short term. Little evidence suggests that existing models can accurately capture SOC change at the field level under all proposed management interventions for all combinations of soils and climate. For both sampling-only and hybrid sampling and modeling approaches, designing an effective soil sampling strategy that adequately captures spatial heterogeneity and reduces uncertainty in SOC stock estimates is essential. Soil sampling details provided by published protocols may prove insufficient, depending on the associated challenges to quantifying SOC and the level of certainty demanded by buyers of credits.

This report outlines research gaps underpinning the understanding of the mitigation potential of SOC sequestration. It details how the various protocols plan to quantify changes in SOC and associated GHGs — nitrous oxide and methane. It includes important considerations in the application of process-based models for GHG estimation, and it highlights technological developments for measuring SOC.

## Different protocol approaches to structural accounting issues

In addition to the technical challenges of SOC quantification, SOC credits must account for issues of additionality, leakage, reversals and permanence, all of which increase the risk of not achieving desired climate benefits.

These structural considerations address whether a specific project results in carbon sequestration that would not otherwise have occurred under a business-as-usual approach (additionality). They ensure a project does not result in increased emissions off-site (leakage), while accounting for and protecting against subsequent losses (reversals) due to changing practices or unplanned climate impacts like fires, floods and droughts. They also consider whether a project achieves permanence of sequestered carbon by accounting for reversals, which is generally approximated as maintenance of the carbon stock over 100 years.

Published protocols address these issues but with varying thresholds. These differences mean that credits derived from different protocols are not equivalent, a significant impediment for applying these credits to NDCs or emission offsets. This underscores the need for consistent oversight to ensure environmental integrity in the generation of credits.

## Mitigating risk and managing uncertainty through accounting at regional scales

Existing protocols rarely define the scale of project implementation, whether at a field-, farm- or aggregated fields level. Grouping together multiple farm-scale projects, known as aggregation, will help reduce transaction costs associated with MRV. Explicitly defining the scale and bounds of aggregation using biophysical and agroecological characteristics would enhance risk mitigation and accounting while greatly reducing measurement MRV costs. Aggregation at an appropriate scale can help with tracking annual variability in climate patterns, crop yields, and broad scale management adoption, allowing for more transparent and feasible accounting and assessment of leakage and additionality.

Furthermore, an aggregated scale would mitigate against the risk of reversal by enabling the accumulation and management of a sufficiently large buffer account. Using an ensemble of process-based models as a component of SOC MRV at large scales would also produce more accurate estimates of mean changes in SOC with reduced uncertainty versus accounting for changes in SOC on a project-by-project basis.

This report suggests a conceptual framework and an example of an aggregation approach, based on tiered land classifications that capitalizes upon existing U.S. Department of Agriculture reporting districts that track relevant statistics for assessing leakage and additionality. The USDA districts could also be used as jurisdictional regions, ensuring a region-wide accounting system.

## Recommendations for a way forward and continued research needs

Paying farmers to sequester carbon remains an uncertain approach to climate change mitigation due to reversal risk and the uncertainties of accurately detecting carbon stock change over time. Direct emission reductions and verified avoided conversion, by comparison, should result in credits that could count toward NDCs or emission offsets.

Because of these uncertainties, companies with agricultural supply chains should only include GHG mitigation through SOC sequestration as part of their scope three reductions. Companies can make the greatest, most certain climate impact by prioritizing direct emissions reductions of methane, nitrous oxide and carbon dioxide. Continued research, pilot projects and advances in MRV will help address the current challenges and uncertainties associated with carbon credits by providing the evidence needed for outcomes to match expectations.

To improve confidence, increase scalability and help ensure carbon credits represent net environmental benefits, EDF recommends that federal policymakers, researchers, protocol and project developers, and food and agriculture companies:

1. Validate and compare net carbon sequestered along with associated uncertainty as estimated by different MRV protocols to help determine the degree to which different published protocols equivalently account for net GHG reductions.

2. Determine the appropriate scale of aggregation and buffer-level accounting based on agroecological, biophysically defined regions and socio-economic attributes to account for additionality and leakage, reduce risks of reversal, help provide MRV cost savings, and support participation of diverse farm operations within any crediting program.
3. Develop high-quality, open-access datasets for model calibration, benchmarking, and baseline and additionality determination.
4. Support the continued development of cost-effective approaches to MRV using emerging technology to help produce accurate and scalable solutions for quantifying net GHG reductions.

**Table 1:**

## Soil carbon estimation and sampling methodologies

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

For information related to these issues and specific to each protocol, see the appendix. Protocols synthesized include 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.

## BOX 1: TERMINOLOGY

**Additionality:** The concept that a project/activity leads to emission reductions or removals that are additional to those that would have happened in the absence of the incentive generated by the crediting mechanism.

**Baseline:** The emissions level corresponding to the scenario under which the project/activity is not awarded the incentive generated by the crediting mechanism.

**Baseline scenario:** The most likely scenario in the absence of the crediting mechanism, including all assumptions on drivers for relevant emission reductions.

**Carbon credit:** The unit that is certified by a carbon credit program or standard for trade in carbon markets, representing one metric tonne of carbon dioxide equivalent.

**Carbon dioxide equivalent:** A metric, often written as $CO_2$-e, used to compare GHGs on the basis of their global warming potential, by converting amounts of other gases, usually nitrous oxide and methane, to the equivalent global warming potential of carbon dioxide. Note that the shorter life span of methane means that the calculation should be done on a 20-year rather than 100-year basis for this gas.[B1-1]

**Carbon inset:** A broad term to describe emission reductions or removals achieved within the supply chain of an entity that are used to compensate for entity emissions; a carbon credit secured through investment within the supply chain of an entity.

**Carbon insetting:** The use of carbon credits, or other units, generated within a company's supply chain to offset a company's emissions or environmental and social impacts.

**Carbon market:** A market in which units — allowances or credits — are traded between entities. When units are used for voluntary purposes or where carbon credits are certified solely by voluntary programs or standards, the market is often referred to as a "voluntary" carbon market. Where units are used to satisfy legal compliance obligations, this is often referred to as a "compliance" market.

**Carbon offset:** A broad term describing a carbon credit. Often used when the carbon credit is generated outside of a country or company supply chain to compensate for the country's or company's emissions.

**Carbon offsetting:** The use of carbon credits, or other units, to compensate for a country's or company's emissions covered by a compliance or voluntary target.

**Carbon stock:** The absolute mass of carbon in a sample of known volume — typically expressed in tonnes per hectare to a specific depth.

**Compliance market:** A market-based measure that establishes a legal obligation on covered entities to retire or surrender carbon credits or allowances to cover their emissions.

**Credit quality criteria:** Criteria that aim to ensure high-quality attributes for carbon credits. There are several initiatives that have sought/are seeking to define high-quality credit criteria.

**Global warming potential:** The global warming potential of a gas refers to the total contribution to global warming over a defined time frame resulting from the emission of one unit of that gas relative to one unit of the reference gas, carbon dioxide, which is assigned a value of one.

**Leakage:** Increased emissions outside of project boundaries as a result of project activities that are intended to reduce or remove GHG emissions (e.g., if net carbon sequestration results in lower productivity, expansion of land under agricultural production may result, increasing emissions and representing leakage).

**Measurement, reporting and verification:** A system or protocol for tracking specific methods and outcomes, transparently communicating specific information, and validating that the information is accurate and complete. Often abbreviated as MRV.

**Mitigation:** A human intervention to reduce emissions or enhance GHG sinks (removals).

**Permanence:** A requirement that the issued carbon credits represent long-term reductions or removals and that measures are in place to mitigate the risk that the reduction or removal is reversed. For SOC projects, the permanence time frame generally requires that projects maintain activities that have led to SOC accrual in order to prevent reversals.

**Protocol:** A guidance document that contains all relevant rules, standards, deductions, calculations and parameters for the calculation/estimation of emission reductions and removals, and for monitoring, verification and reporting of emission reductions and removals from an emissions crediting project.

**Reversal:** A loss in carbon that was previously sequestered, due to harvesting, clearing, weather or management practices. Reversal risk is directly related to permanence.

**Scope one emissions:** A company's direct emissions from owned or controlled sources.

**Scope two emissions:** A company's indirect emissions associated with purchase of power, heat, steam or cooling.

**Scope three emissions:** A company's indirect emissions that occur in their value chain, including both upstream and downstream emissions.

**Soil carbon sequestration:** The net additional storage of carbon from atmospheric carbon dioxide in soil pools, after accounting for any GHG losses.

**Soil organic carbon:** The carbon contained within soil organic matter. Often abbreviated as SOC.

**Soil organic matter:** The fraction of soil that consists of decomposed plant, animal and microbial material.

**Verification:** The process whereby an accredited third-party verifier examines or reviews a project, including the methodology and emission reduction or removal calculations, that the regenerative practices are occurring on farm and that SOC is being properly accounted for.

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[B1-1] Ocko, I. B., S. P. Hamburg, D. J. Jacob, D. W. Keith, N. O. Keohane, M. Oppenheimer, J. D. Roy-Mayhew, D. P. Schrag, and S. W. Pacala. 2017. Unmask temporal trade-offs in climate policy debates. Science 356:492–493.

# Introduction

Soils represent one of the largest terrestrial carbon stocks on Earth. Land use change and conversion of native soil to agriculture has led to significant reductions in that stock.[3,4] This loss of organic matter, with its associated reduction in soil fertility, threatens crop yield stability and environmental quality across the globe.[5,6,7] The resulting land degradation decreases food security, diminishes rural livelihoods and threatens freshwater systems.

In response, initiatives ranging from advocacy campaigns to state and federal policy creation to private sector incentive programs — examples include 4 per mille, California's Healthy Soils Program and Indigo Carbon — have been developed to restore soils. These efforts rest on the premise that increasing the amount of SOC will both restore agricultural lands through a shift to more sustainable practices and sequester atmospheric carbon dioxide.

In recent years, carbon registries and private companies (see Table 1) have developed SOC MRV protocols to bring verified carbon credits to the market and pay farmers for sequestering carbon. Additionally, the Biden administration is considering establishing a USDA-led carbon bank[8] or other mechanism to scale the adoption of emissions-reducing and carbon-storing agricultural practices.

These protocols and the promise of carbon markets rest on research showing that certain agricultural management practices effectively sequester SOC. For instance, reduced and no-tillage, retaining crop residues, cover cropping, diverse crop rotations and fertilizer management have shown improvements in SOC levels compared to conventional modes of agriculture that rely on more frequent tillage and less diverse cropping systems.[9,10,11,12,13]

SOC MRV protocols apply this research to help farmers generate credits for verified emissions reductions and carbon sequestration. Farmers can then sell these credits to companies for use in voluntary carbon markets as part of corporate sustainability efforts or in compliance markets, if protocols have regulatory approval, to satisfy climate mitigation compliance requirements.

As momentum grows for crediting farmers to sequester SOC, it is essential that any credits generated be based on accurate estimates of net carbon stored. To that end, there is a pressing need to ensure SOC MRV protocols result in high-quality credits that represent real net GHG reductions. Differences in the way protocols and carbon marketplaces estimate carbon and net GHG reductions, as well as the way they account for issues such as permanence of carbon sequestered, run the risk of creating credits that are not equivalent (see Box 2). This is especially problematic if SOC credits are used to meet U.S. NDCs or sold as offsets to sectors required to reduce emissions.

**In this report we:**

- Provide an overview of critical knowledge gaps in the scientific understanding of management impacts on SOC sequestration.
- Specify limitations and key uncertainties associated with different SOC quantification approaches.
- Share a summary of available SOC MRV protocols specifically for improved agricultural lands (see Table 1 and the Appendix A).
- Highlight the lack of quantitative guidance in existing SOC MRV protocols when it comes to providing sampling strategies for effectively detecting change in SOC over time.
- Synthesize how the different protocols approach issues such as additionality, reversals, permanence and the quantification of net GHG reductions.
- Outline critical research needs to solidify the footing upon which emerging carbon credits currently stand.

## BOX 2: INVESTING IN AGRICULTURAL CLIMATE SOLUTIONS

Climate mitigation opportunities in agriculture include reducing on-farm fuel consumption, rebuilding soil organic matter, increasing aboveground and belowground biomass, improving nutrient management and reducing methane emissions associated with livestock production.

While much of the current attention is focused on SOC sequestration, the opportunities to reduce emissions associated with agricultural activities are equally worthy of consideration, as their mitigation potential is large, and they have many advantages over SOC sequestration as a mitigation strategy.

For instance, reduction of fuel consumption, methane emissions or fertilizer inputs results in avoided emissions that are permanent and therefore do not have the risk of reversal. Without the risk of reversal, there is no need for risk management requirements like maintaining a GHG offset credit buffer. Avoided emissions are also immediate, unlike SOC sequestration, which takes many years to accumulate to measurable levels.

As noted in this report, protocols use process-based models, soil sampling or both to estimate SOC sequestration. Soil samples taken in year five could potentially demonstrate that modeled estimates were greater than measured rates of SOC accrual. Depending on who assumed the initial risk, an overestimation could result in delayed payments until measured SOC accrual matches modeled estimates or requirements to use buffer credits to make up the difference.

Thus, SOC sequestration offset credits are risky investments. It will take several years to determine if they are beneficial and will require continued monitoring to ensure that the SOC sequestered is not lost through changes in management practices. The expected duration of SOC sequestration is typically set at 100 years, although most protocols have much shorter required periods of permanence. This inconsistency demonstrates a dilemma that is not yet resolved, adding further risk to investments in SOC sequestration.

An important avoided emissions opportunity for farmers is the reduction of nitrous oxide emissions from soil. Nitrous oxide is a potent GHG with a global warming potential of 265 over 100 years or 264 over 20 years.[B2-1] Agricultural soils are responsible for 78% of nitrous oxide emissions in the U.S., representing about 5% of total GHG emissions on a 100-year time frame.[B2-2] By optimizing manure and inorganic fertilizer application, many farmers can save money and reduce nitrous oxide losses from soils, while also reducing nitrate leaching and providing water quality benefits.

Empirical modeling has shown that as the N balance — nitrogen input minus nitrogen removed — increases, the percentage of applied nitrogen lost as nitrous oxide and nitrate increases at an accelerating rate.[B2-3] Thus, targeting those farms where N balance is high represents an opportunity to gain substantial GHG emission reductions with little risk of yield impacts, as well as cost savings for the farmer. Reducing fertilizer nitrogen application also has the indirect GHG benefit of reducing the fossil GHG emissions released during the manufacturing and transport of the fertilizer.

For livestock producers, reduction of emissions of methane represents a valuable opportunity to generate revenue while reducing a potent short-term climate warming gas. Methane's atmospheric lifetime averages a little over a decade, and its global warming potential over 20 years is 84. Reduction in methane emissions can have major impacts on the rate of warming over the next few decades.[B2-4]

Capturing biogas, which is usually more than half methane, currently emitted from manure management systems can provide permanent, immediate climate benefits, as well as revenue since biogas can be processed to pipeline-grade methane.

Livestock also produce methane via enteric emissions. Work is underway to develop feed additives or diet changes to reduce enteric emissions, and protocols to credit those avoided methane emissions are being considered. However, getting such feed additives to grazing beef cattle, where most livestock methane emissions occur, will be a challenge.

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[B2-1] Pachauri, R. K., M. R. Allen, V. R. Barros, J. Broome , W. Cramer, R. Christ, J. A. Church, L. Clarke, Q. Dahe, P. Dasgupta, and N. K. Dubash. 2014. Climate change 2014: synthesis report. Contribution of Working Groups I, II and III to the fifth assessment report of the Intergovernmental Panel on Climate Change (p. 151). IPCC.

[B2-2] U.S. EPA. 2021. Draft Inventory of U.S. Greenhouse Gas Emissions and Sources. EPA.

[B2-3] Eagle, A. J., E. L. McLellan, E. M. Brawner, M. H. Chantigny, E. A. Davidson, J. B. Dickey, B. A. Linquist, T. M. Maaz, D. E. Pelster, C. M. Pittelkow, C. Kessel, T. J. Vyn, and K. G. Cassman. 2020. Quantifying On-Farm Nitrous Oxide Emission Reductions in Food Supply Chains. Earth's Future 8:e2020EF001504.

[B2-4] Ocko, I. B., S. P. Hamburg, D. J. Jacob, D. W. Keith, N. O. Keohane, M. Oppenheimer, J. D. Roy-Mayhew, D. P. Schrag, and S. W. Pacala. 2017. Unmask temporal trade-offs in climate policy debates. Science 356:492–493.

# Research gaps underlying the premise of emerging soil carbon markets

Soil scientists generally agree that a large proportion of agricultural soils have lost SOC. The top 30 cm (~1 foot) of the world's agricultural soils has been estimated to contain 263 Pg of organic carbon, having lost an estimated 31 Pg from anthropogenic land use changes over the last 12,000 years.[14]

Practices that reduce soil disturbance, increase the amount of organic inputs into the soil, retain plant residues and keep plants in the ground are generally understood as practices that can restore or enhance at least some of the lost SOC in surface soils by building soil health through improved soil structure and nutrient and water retention. There is a lack of scientific consensus, however, about the degree to which these practices can sequester sufficient atmospheric carbon to have an appreciable impact in mitigating climate change.[15,16,17]

This uncertainty stems in large part from a lack of data on the spatial and temporal patterns of SOC across agricultural landscapes. The amount of SOC can vary markedly across a field due to pronounced differences in biophysical and landscape conditions such as soil moisture, soil texture and slope. Long-term datasets of agricultural field trials do not necessarily capture this variation because researchers often implement treatments across replicated field blocks to reduce and eliminate the influence of soil variability.

Many of these long-term datasets also lack a baseline measurement of SOC and corresponding bulk density values, limiting the capacity to resolve the true trajectory of SOC stocks over time and in response to specific management interventions.[18]

Some empirical data for which there are baseline measurements have revealed reductions in SOC under both conventional and improved management systems, albeit improved management practices might show slower rates of loss.[19,20] Related and contributing to this lack of spatial and temporal resolution: increases in SOC occur slowly and can be difficult to detect without a very high density of soil samples (see Figure 1).[21,22]

The process of sampling and analyzing soils for SOC is time intensive, expensive and requires a high degree of analytical accuracy to limit analytical variance.[23]

Management treatments in long-term agricultural field trials are not necessarily reflective of working farm practices, further limiting the understanding of their impacts on SOC. For example, field trials often introduce large amounts of inputs such as manure and compost, which may not be accessible to most farmers.[24,25] Such practices may only shift carbon from one location to another and don't actually lead to net sequestration.

Furthermore, the typical on-farm practice of no-till in alternate years or other no-till interruptions differs from no-till research trials that measure outcomes after continuous no-till over many years. Thus, trial results often result in larger apparent carbon benefits than those that are found in commercial fields.[26]

The impact of agricultural management on net emission reductions represents another critical knowledge gap. Agriculture is a significant source of anthropogenic nitrous oxide, methane and carbon dioxide emissions, and efforts using soil as a natural climate change solution must account for unintended consequences or potential trade-offs resulting from shifts in practices. For example, agricultural practices that build SOC could potentially result in increased nitrous oxide emissions, which could offset gains in SOC sequestration.[27,28] Quantifying this potential trade-off is difficult, however, because nitrous oxide emissions vary temporally and spatially and constitute an uncertain component of agricultural GHG budgets.[29] The use of metrics such as nitrogen balance — the difference between nitrogen inputs and outputs — can help approximate on-farm nitrogen losses to understand management impacts on these potential trade-offs.[30]

These empirical data gaps generate a lack of confidence and high uncertainty when it comes to our understanding of the capacity for improved agricultural management to generate meaningful and lasting reductions in atmospheric carbon through SOC sequestration. Efforts to integrate data and existing knowledge are underway (e.g., OpenTEAM, CIRCASA) and will increase scientists' understanding of agricultural management impacts on SOC sequestration across a diversity of working farms.

# Technical considerations for emerging soil carbon markets: Measurement and uncertainty

SOC sequestration projects as developed under different MRV protocols need to provide real, net GHG reductions to produce high-quality credits that could be used to meet national GHG commitments or to offset emissions in regulated sectors.

These reductions are difficult to quantify due to the unique challenges of measuring SOC. Measuring SOC is time intensive and expensive, which limits the scale at which data are collected.[31] More data is necessary to determine whether a change in SOC will be large enough and fast enough for researchers to detect it against background variation in SOC. The estimated cost of measurement remains high at U.S. $32 per hectare),[32] while the price of carbon credits as announced by many of the emerging carbon crediting organizations (U.S. $10-$15 per credit)[33] precludes soil sampling at a density that would provide high levels of confidence in the ability to detect meaningful change.

The protocols in this report use different approaches for measuring and monitoring SOC and other GHGs. (See Table 1 and the Appendix A). Protocols are based on soil sampling only; modeling that uses either process-based biogeochemical models, empirical models or emissions factors to estimate GHG emission reductions of carbon dioxide, nitrous oxide and methane; hybrid approaches that require both soil sampling and the use of models; or remote sensing that relies on satellite imagery verified by soil sampling.

## Key sampling issues: Capturing spatial and temporal variability

Soils must be sampled in a manner that captures field-scale variability to provide an unbiased estimate of the mean. Strategies such as stratification — division of the project area into zones of similar soil type, slope and elevation — of the landscape create more efficient sampling designs to capture the distribution of SOC across a given landscape.[34] Capturing spatial heterogeneity is critical to improving the accuracy of SOC estimates while potentially reducing the number of soil samples required to estimate mean SOC content across a landscape.

Most protocols either recommend or require some level of stratification prior to sampling soils. However, none of the protocols provide quantitative approaches to help guide stratification; they remain very qualitative. Australia's SOC monitoring protocol and FAO's Global Soil Organic Carbon (GSOC) MRV protocol are the only ones that include a minimum number of strata (at least three) and a minimum number of samples per strata (at least three).

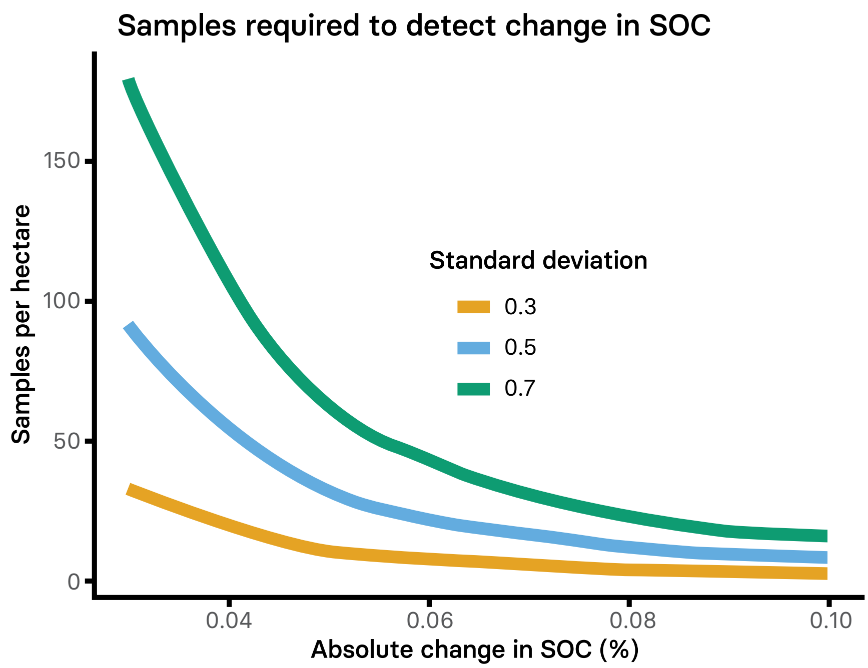
For protocols that do require stratification, returning to the same strata in each successive sampling round might help reduce variability over time, but very few of the protocols provide any guidance for the use of paired sampling locations over time. Permanent sampling locations could lead to "gaming the system," but collecting independent samples at each monitoring round increases the degree of variability that might make detecting change in SOC very difficult.

The Climate Action Reserve Soil Enrichment Protocol (CAR SEP) allows for remeasurement on no more than 50% of previous sampling points, and FAO's GSOC MRV allows for returning to previous sampling locations, provided they are offset by a few feet. Verra's Soil Carbon Quantification Methodology (VM0021) is the only protocol that calls for the establishment of permanent soil sampling plots, but no one has adopted this protocol since it was published in 2011.

Given that there are no specifications related to project scale across any of the protocols, the minimum strata and sampling efforts specified could result in woefully inadequate coverage to detect meaningful changes in SOC over time with a degree of confidence that can support robust carbon credits.

Some protocols that rely on soil sampling (Verra VM00021 and FAO GSOC MRV) recommend that power analysis be performed at an acceptable level of uncertainty to determine a minimum number of samples to take. To inform the power analysis, which requires some level of knowledge regarding the variation of SOC across the project area, protocols recommend conducting reconnaissance pre-sampling. This may or may not be feasible given the extra resources it requires. Figure 1 presents results from a traditional power analysis across a hypothetical field of 50 hectares (124 acres), demonstrating the sample sizes necessary to detect different levels of absolute change in SOC concentrations depending on the degree of variability (standard deviation). Field-scale estimates of variability differ and can range from relatively low variability (standard deviation of 0.2) to more highly variable (standard deviation of 1.0).[35,36,37]

**Figure 1: Results from a traditional power analysis at 95% confidence with power of 0.8 performed for different levels of field variability on a 50-hectare farm**




This power analysis was designed to determine the number of samples per hectare necessary to detect an absolute change in SOC across a range from 0.03 to 0.10% (i.e., going from 2.0% to 2.03% or 2.1%). We chose this range to encompass a commonly cited rate of SOC accumulation under cover cropping (0.3 t C $ha^{-1}$ $yr^{-1}$). Over five years, this would add up to an increase of 1.5 tC $ha^{-1}$, which amounts to an increase of 0.05% in SOC concentration (focusing on the top 30 cm and assuming a bulk density of 1 g $cm^{-3}$). The power analysis assumes independently sampled points at each time period.

In addition to uncertainty about the number of samples required to detect SOC change, scientists and practitioners also face uncertainty about the amount of time required to observe measurable increases in SOC. A synthesis of agricultural experiments in the U.S. showed time frames between 11 years and 71 years to detect statistically significant changes in SOC stocks,[38] despite a small-plot experimental design that eliminated much of the inherent variation in soils found in real farms.

Other published rates of SOC accumulation from long-term research in temperate agricultural systems range from 0.3% to 18% of initial SOC concentrations.[39] Assuming an initial starting concentration of 1.5%, achieving 2% SOC would take about 75 years with a constant annual relative rate of increase of 0.4%, the global target set out by the 4 per mille initiative. Thus, the combination of spatial variation and slow SOC accumulation rates makes it difficult to accurately quantify discernible changes in SOC.

Emerging measurement techniques (see Box 3) that allow for a 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.[40,41] Some protocols already allow for estimates of SOC using soil spectroscopy (AUS-SM, FAO GSOC). The development of in-field sensors also presents a promising approach to capture accurate SOC estimates over large, heterogeneous landscapes.[42]

Because SOC is heavily context dependent, requiring a set number of strata and soil samples within a protocol is likely not feasible or useful. Establishing a baseline through soil sampling is critically important to help determine the trajectory of change in SOC. Most sampling-only and hybrid protocols do require an initial baseline.

Quantitative guidance regarding stratification — what method to employ and recommendations for number of strata given the size of the project area — could provide useful guidance to help reduce variation in modeled and sampled SOC estimates.

## BOX 3: TECHNOLOGICAL DEVELOPMENTS FOR MEASURING SOC

In response to the unique challenges of quantifying SOC, the public and private sectors are investing in various efforts to reduce the costs of monitoring and verification without sacrificing accuracy. The Department of Energy's ARPA-E Smart-Farm Program is investing in technology to advance MRV capabilities. Funded projects range from soil sensors building off advances in soil spectroscopy to combined process-based model and remote sensing approaches to quantify field-level GHGs.

Advances in spectroscopy present an alternative to dry combustion methods and can address the need for long-term monitoring at a reduced cost. Organic matter and soil minerals absorb light at different wavelengths, enabling estimation of a number of soil properties from low-cost, high-throughput measurements of light absorbance in the visible, near-infrared and mid-infrared regions of the electromagnetic spectrum.[B3-1,2]

Already a well-established technology in the research domain, private sector startups are capitalizing on these advancements to present the business case for spectroscopy as a scalable SOC MRV solution. For example, Yard Stick, a probe that attaches to a hand-held drill, has a tiny camera that captures infrared light reflected off the soil and includes a resistance sensor for bulk density measurement. The Yard Stick device is currently undergoing testing against traditional bulk density and SOC quantification methods in summer 2021. It aims to eliminate the need for traditional soil sampling to produce an instant estimate of SOC.

Remote sensing technologies are also under discussion as scalable solutions to MRV but are still in early phases of development. For instance, some remote sensing products can track agricultural yields and adoption of conservation agricultural practices, such as no-till and winter cover cropping. Examples include OpTIS[B3-3] and Descartes Lab products. Such information could be quite useful for parameterizing models, as well as for determining additionality and leakage for SOC sequestration projects developed under various protocols.

With the proliferation of higher-resolution, satellite-based sensors, there is growing research linking these remotely sensed spectral signatures over bare ground to measured SOC data.[B3-4] This work generally shows promise for mapping the spatial distribution of surface SOC concentrations under ideal conditions.[B3-5]

Vegetation, crop residues and variable soil moisture conditions all confound the direct use of remote sensing to estimate SOC, so while there is limited but growing success in mapping surface SOC concentration over bare fields, there has been no demonstrated proof that remote sensing alone can account for changes in SOC stocks to at least 30 cm over time thus far. It is critical that these efforts be evaluated in terms of their efficacy of achieving accuracy and precision when it comes to detecting changes in SOC.

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[B3-1] Dangal, S., J. Sanderman, S. Wills, and L. Ramirez-Lopez. 2019. Accurate and Precise Prediction of Soil Properties from a Large Mid-Infrared Spectral Library. Soil Systems 3:11.

[B3-2] Wijewardane, N. K., S. Hetrick, J. Ackerson, C. L. S. Morgan, and Y. Ge. 2020. VisNIR integrated multi-sensing penetrometer for in situ high-resolution vertical soil sensing. Soil and Tillage Research 199:104604.

[B3-3] Hagen, S. C., G. Delgado, P. Ingraham, I. Cooke, R. Emery, J. P. Fisk, L. Melendy, T. Olson, S. Patti, N. Rubin, B. Ziniti, H. Chen, W. Salas, P. Elias, and D. Gustafson. 2020. Mapping Conservation Management Practices and Outcomes in the Corn Belt Using the Operational Tillage Information System (OpTIS) and the Denitrification–Decomposition (DNDC) Model. Land 9:408.

[B3-4] Angelopoulou, T., N. Tziolas, A. Balafoutis, G. Zalidis, and D. Bochtis. 2019. Remote Sensing Techniques for Soil Organic Carbon Estimation: A Review. Remote Sensing 11:676.

[B3-5] Castaldi, F., A. Hueni, S. Chabrillat, K. Ward, G. Buttafuoco, B. Bomans, K. Vreys, M. Brell, and B. van Wesemael. 2019. Evaluating the capability of the Sentinel 2 data for soil organic carbon prediction in croplands. ISPRS Journal of Photogrammetry and Remote Sensing 147:267–282.

Improvements in regional soil mapping show promise for providing prior information that could help inform sampling efforts. Technology developments such as web-based applications could also help project developers and farmers establish quantitatively backed stratification approaches that incorporate relevant data layers and available soil information. These improvements to sampling design, coupled with technological advances for measuring and estimating SOC, will help develop accurate, scalable and cost-effective measurement-based approaches to SOC MRV (see the "Defining the project scale" section below).

## Key sampling issues: Soil carbon at depth and equivalent soil mass

Understanding both SOC at depth and changes to soil bulk density are critical accounting issues for calculating accurate carbon stock estimates. All soil sampling protocols require taking samples to 30 cm. CAR's SEP and the FAO GSOC protocol recommend sampling to one meter, though it is not required. Verra's VM0021 — based on sampling requirements set out in VMD0021 — is the only protocol that requires taking samples to at least one meter, with the ultimate recommendation of reaching two meters.

Measuring SOC at depth provides the most complete picture of how carbon stocks change due to management. For instance, practices such as no-till have shown a redistribution of SOC across depth profiles to one meter, resulting in no net change in SOC under no-till.[43] A recent meta-analysis shows gains in SOC under no-till within the top 30 cm coupled with an approximately 50% reduction in overall gains when soils were measured at depth (0 cm-60 cm).[44] Because of the uncertainty of no-till impacts on SOC stocks across the soil profile, converting from deeper tillage practices to reduced or no-till are not eligible under CAR's SEP.

In addition to the need to accurately capture SOC stocks at depth, only two of the protocols (FAO GSOC and Australia's Carbon Farming Initiative) require calculating carbon stocks using an equivalent mass basis to account for potential changes in soil bulk density. When calculating stocks, it is critical to account for reductions in bulk density through improved management practices that effectively reduce the soil mass in the upper soil layer.[45]

Sampling protocols, such as Australia's sampling methodology and FAO GSOC MRV that require taking soil samples with a minimum of two depth increments, can account for potential changes in bulk density for more accurate accounting of SOC stocks. Other protocols, such as CAR's SEP, recommend accounting for equivalent soil mass but only require a single measurement to 30 cm.

## Key modeling issues: Uncertainty, scale of model inputs and applicability

Even with emerging measurement techniques, cost-effective sampling cannot easily detect changes in SOC at the field scale and within market-appropriate time frames.[46] Appropriately calibrated and validated models can extrapolate over space and time to assess SOC and other relevant GHG outcomes, potentially reducing costs and allowing for finer time increments. For example, given the inability to detect annual changes in SOC, a predictive model would be necessary for a market to credit farmers annually.

A number of protocols (CAR SEP, VM0042, FAO GSOC, Gold Standard's SOC Framework Methodology and BCarbon) employ hybrid approaches that combine process-based models with direct field measurements of SOC to verify model predictions. There are several key considerations when employing process-based models for SOC MRV: the level of expertise required to run the model; whether the model is appropriately calibrated and validated to a project area; the scale of input data and model deployment; and the degree of certainty in predicted SOC stock, stock change and other GHG fluxes.

Project developers are more likely to use models with relatively accessible interfaces within an internet application or browser that can be used without involving outside expertise. However, there may be a trade-off between efficiency and complexity. Even with clear guidance documentation, unless those running the model possess a sufficient combination of technical and domain expertise, they may inadvertently misapply or misinterpret the data.

The quality and quantity of available measured data to support modeling efforts are critically important for modeling SOC, including changes in SOC. While scientists use empirical understanding to develop the soil-plant system processes estimated within models, the outcomes' adherence to reality relies on sufficient calibration and validation across the range of environmental and agricultural practice combinations.[47]

Advances in computing power and scientific network efforts have increased the volume of globally applicable soil data available for model calibration and evaluation.[48] Such validation, with choices about the appropriate extrapolation of models beyond empirical bounds, would preferably precede application within a carbon sequestration protocol. Implementation of a model within a project itself will have quite different data requirements, ranging from delineation of soil and climate zones to historical management. Some of these inputs may have a seemingly outsized influence on model output, so that slight changes in factors like the crop rooting depth could have a greater impact on organic matter cycling than the precisely described tillage system.

It is essential that connections between activities (practice combinations) and estimated net carbon sequestered are directionally correct, since the outcomes will guide programs and markets. This assessment requires accuracy in both the starting point (SOC stock) and in the trend over time (change in SOC). To maximize the likelihood of success in both of these areas, model guidance for practitioners should carefully outline the cropping systems, regions and management practices that can be modeled, as well as those for which uncertainty may be too high for appropriate deployment.[49]

SOC biogeochemical models can, in theory, be deployed at different scales, from sub-field to farm to region. However, measurement error can significantly impact uncertainty in site-level predictions, and model evaluation has suffered from lack of clear error quantification within existing databases.[50] Thus, measured SOC stocks used as data inputs for models may only represent one to a few replicates for a given site. This can lead to high measurement error, which increases site-level uncertainty of SOC estimates.[51] A 2010 study exploring the impact of scale on process model estimates of changes in SOC showed that uncertainty was inversely related to scale with uncertainties of approximately 20% at a national scale ballooning to 600%-700% at the site scale.[52] Models alone may be inadequate for SOC estimation at site-level scales, unless project developers adequately calibrate for areas and crops.[53]

Predicting SOC stocks and stock changes over regional scales can reduce the uncertainty of modeled estimates. These advantages of larger scales suggest that regional aggregation of projects would result in greater precision with lower measurement effort. Aggregation may not, however, address accuracy or the unbiased ability to predict net GHG outcomes.

Any remaining uncertainty would need to be managed through discounting of credits awarded or other insurance mechanisms within a protocol. Regular, standardized comparisons of model results with measured data from multi-field projects would be useful for assessing potential bias, as well as for determining the appropriate geographic and time scales for a desired level of confidence with the anticipated SOC change (see Box 4).

# BOX 4: ADVANCING MRV THROUGH MODEL BENCHMARKING EFFORTS

While a hybrid approach that combines in situ measurements with process-based models is likely a better solution than relying on process-based models alone, protocols need to improve the accuracy and scalability of the models by benchmarking them with independent and high-quality measurements from soil sampling. (See the Recommendations section.)

Most recommended models currently require a very high level of specialized knowledge and a deep dive into the scientific literature to understand their overall performance and quality.

Development of an open-model registry with common performance metrics would greatly reduce the current opacity in soil carbon models. A set of sites that have long-term records of all required model inputs — including management records, soil properties, climate data and yield — and outputs — carbon fluxes including gross primary production and carbon dioxide respiration, nitrogen fluxes and long-term SOC change — can serve as primary calibration and validation sites.

In addition, a larger set of auxiliary sites located in important crop production zones could provide a reduced suite of measurements — crop yields, SOC, bulk density and N balance — to allow for true, out-of-sample model validation within each production zone in which the model will be applied.

Existing research networks such as the USDA Agricultural Research Service's Long-term Agroecosystem Research Network, some of the National Science Foundation's Long-term Ecological Research Network and the NSF National Ecological Observatory Network, in combination with research stations at many land-grant institutions and other research centers, can provide the backbone for such a model benchmarking effort.

Much of the data necessary already exists,[B4-1] but it will require a concerted effort to bring together these disparate data sources and ensure interoperability. Once existing data streams are identified, gaps in geographic data collection can be identified and targeted as new auxiliary sites in this benchmarking effort.

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[B4-1] Paustian, K., S. Collier, J. Baldock, R. Burgess, J. Creque, M. DeLonge, J. Dungait, B. Ellert, S. Frank, T. Goddard, B. Govaerts, M. Grundy, M. Henning, R. C. Izaurralde, M. Madaras, B. McConkey, E. Porzig, C. Rice, R. Searle, N. Seavy, R. Skalsky, W. Mulhern, and M. Jahn. 2019. Quantifying carbon for agricultural soil management: from the current status toward a global soil information system. Carbon Management 10:567–587.

# Structural considerations of emerging carbon markets: Additionality, leakage, reversals and permanence

Within each protocol, structural considerations address whether agricultural practices implemented under a project activity result in net GHG reductions or sequestration that would not otherwise have occurred under a business as usual approach (additionality), do not result in increased emissions off-site (leakage), account for and protect against subsequent losses (reversals) due to changing practices or unforeseen climate impacts, and is permanently sequestered (permanence). Specifics for each protocol are outlined in Appendix A and B with a general overview provided in the following paragraphs.

## *Additionality*

Addressing additionality requires proof that project activities would not have occurred without the incentive structure provided by the carbon market. The protocols assessed in this report have different standards for meeting thresholds of additionality.

Climate Action Reserve's Soil Enrichment Protocol (CAR SEP), Verra's Methodology for Improved Agricultural Land Management Protocol and Gold Standard's Soil Organic Carbon Framework Methodology use a performance standard approach, which requires project activities to show that practices impacting SOC storage are not already being implemented on a defined percentage of land area containing a project (>50% in the case of the CAR SEP protocol, >20% for Verra and >5% for Gold Standard). These differences in defined percentages mean that a project eligible under CAR SEP might not be eligible under Gold Standard's SOC Framework.

Legal requirement tests defined within protocols stipulate that there is no additionality if specific practices are required by law (CAR SEP and Gold Standard SOC Framework Methodology). Other protocols require project owners to show (based on reasonable evidence, modeling results or historic farm records) that they have not previously deployed the same or similar management interventions and that the new management will result in increased SOC storage compared to a business-as-usual/baseline approach.

Encouraging early adopters to continue beneficial practices while also ensuring any credits are truly additional is a challenge. For instance, Nori allows for back payments, so farmers can accumulate credits for practices undertaken over the past five years. BCarbon awards credits for SOC sequestration after the initiation of testing. Less-stringent additionality requirements help ensure that these early adopters do not abandon their practices to re-adopt later for eligibility in the market.

CAR SEP assessed USDA's National Agricultural Statistics Service data on practice adoption rates within specific counties and compiled a "negative list." For practices on this list, projects are ineligible for single-practice adoption if the penetration rate is >50% based on cropland acres within each county. However, if a single practice on the negative list combines with an additional practice (e.g., no-till plus cover cropping), then the entire stack counts as additional.

Alberta's Quantification Protocol for Conservation Cropping dealt with early adoption by establishing a "moving baseline" to accommodate both early and late adoption of reduced and no-till. The sequestration coefficient derived for each eligible region in Alberta is discounted according to the adoption rates of reduced and no-till. This allows early adopters to participate and maintain their practice, while later adopters receive a discounted sequestration coefficient, even though only the latter would truly count as "additional."

### *Leakage*

Leakage results when GHG emissions increase outside of the project area as a result of project activities. Most of the protocols include examples like shifting crop production to other lands to compensate for yield reductions or displacement of livestock outside of the project area. Most protocols explicitly account for yield reductions by requiring projects to prove that yield reductions are no greater than 5% of baseline yields. Projects must also show that the level of grazing activity is not lower than the average level in the historic baseline period. Appropriately defining a "leakage area" and accounting for increased emissions within that area resulting from project area activities remains a challenge.

### *Reversals*

Reversals in carbon sequestration can result from a change in land use or management, such as repeated tillage events after no-till, or from uncontrollable climate events, such as droughts, floods and fires. Protocols have different approaches to account for these types of risk. CAR, Verra, Gold Standard, Regen Registry, BCarbon and the Australian Carbon Farming Initiative all require that a certain percentage of credits go into buffer pools to account for the risk of both unavoidable and avoidable reversal. If an avoidable reversal occurs, the project owner must typically relinquish a quantity of credits equal to the size of the avoidable reversal, or payments cease until the loss of SOC is accounted for.

Nori's approach to reversals differs slightly. During their pilot, Nori is paying farmers in both cash and an equivalent number of restricted tokens — a cryptocurrency that is restricted for 10 years. If a supplier intentionally releases carbon or makes a fraudulent carbon claim, Nori will determine the amount of carbon released, quantify this value into Nori Removal Tonnes and recover the equivalent value of those tonnes from the restricted tokens.

### *Permanence*

Related to the risk of reversal is permanence. Permanence is critical if emission reductions were sold as offsets, as large emitters may be purchasing these credits to offset continued GHG emissions.

The period of permanence is inconsistent across protocols. The United Nations' Intergovernmental Panel on Climate Change defined a 100-year timeframe for monitoring permanence, in combination with determining global warming potential over the same time frame.[54] Arguments in favor of a shorter permanence period stem from the 100-year monitoring timetable — a significant obstacle for projects, especially since projects only receive payments during the first 20-30 years of the project.

CAR SEP, Verra's VM0042 and the Australian Carbon Farming Initiative protocols are the only protocols that include a 100-year permanence period, but they have different mechanisms to ensure permanence. CAR's SEP has less-intensive monitoring requirements during the permanence period. The protocol mandates evidence to support that no reversals have occurred (e.g., through remotely sensed methods) and information related to ongoing activities on the site (e.g., management logs and records).

The Australian protocols stipulate that project owners properly document carbon maintenance obligations over the course of the permanence period with the land title. CAR's SEP and Australia's protocols also have different discounting measures to enable projects to receive credits without committing to a 100-year permanence period. For instance, CAR's SEP developed tonne-year accounting for which credits are issued as a proportion of the 100-year permanence time frame. Similarly, the Australian Carbon Farming Initiative protocols allow projects to elect for a 100- or 25-year permanence period. If projects elect for 25 years, then 20% of the carbon credits will be deducted over the project crediting period.

Other protocols require permanence only over the course of the crediting period, using reversal buffers to account for any loss. Regen Registry, BCarbon and Nori have shorter permanence periods. Nori requires projects to report operating data to prove carbon sequestration for 10 years from the date of their last carbon removal tonne sale, after which projects can elect to enter an additional 10-year contract. BCarbon requires an initial permanence period of 10 years, which is renewable each subsequent year when new credits are issued. Transactions may occur annually, which creates a rolling 10-year commitment. The Regen Network requires a 25-year permanence period with projects either allocating an additional 5% of each credit issuance (in addition to a reversal buffer pool) to a dedicated permanence buffer pool or registering a covenant (a set of rules regarding land use) on project land from project registration until the end of the 25-year permanence period.

# Assessing overall climate impact

It is critically important that carbon markets account for potential increases in other potent GHGs — especially nitrous oxide and methane — that might accompany project activities. All protocols except Nori and BCarbon refer to net GHG emissions resulting from project activities. However, there are key differences with how protocols account for overall emission reductions — including carbon sequestered in the soil, nitrous oxide and methane.

Most protocols use emissions factors or process-models to quantify net GHG emissions resulting from project activities. Emissions factors, such as those developed by the IPCC, provide broad-based estimates of these GHGs resulting from activities such as fertilizer use, increased fuel/electricity use and livestock management.[55]

Nori assumes that project activities will not result in a net increase in total farm GHGs and does not account for non-target GHGs in its methodology. Some protocols allow for estimates of other GHGs to count toward emission reductions. Other protocols only account for increases in GHGs if they are above the baseline and, therefore, don't credit potential GHG reductions. Differences in net emissions accounting could exacerbate the issue of protocol-dependent credits being calculated for the same field and data.

# Defining the project scale

Existing protocols rarely define the scale of project implementation (i.e., field, farm, aggregated set of fields). Aggregation, or grouping multiple participating farms that have similar biophysical and agroecological characteristics would enhance risk mitigation and accounting,[56] while greatly reducing MRV costs.

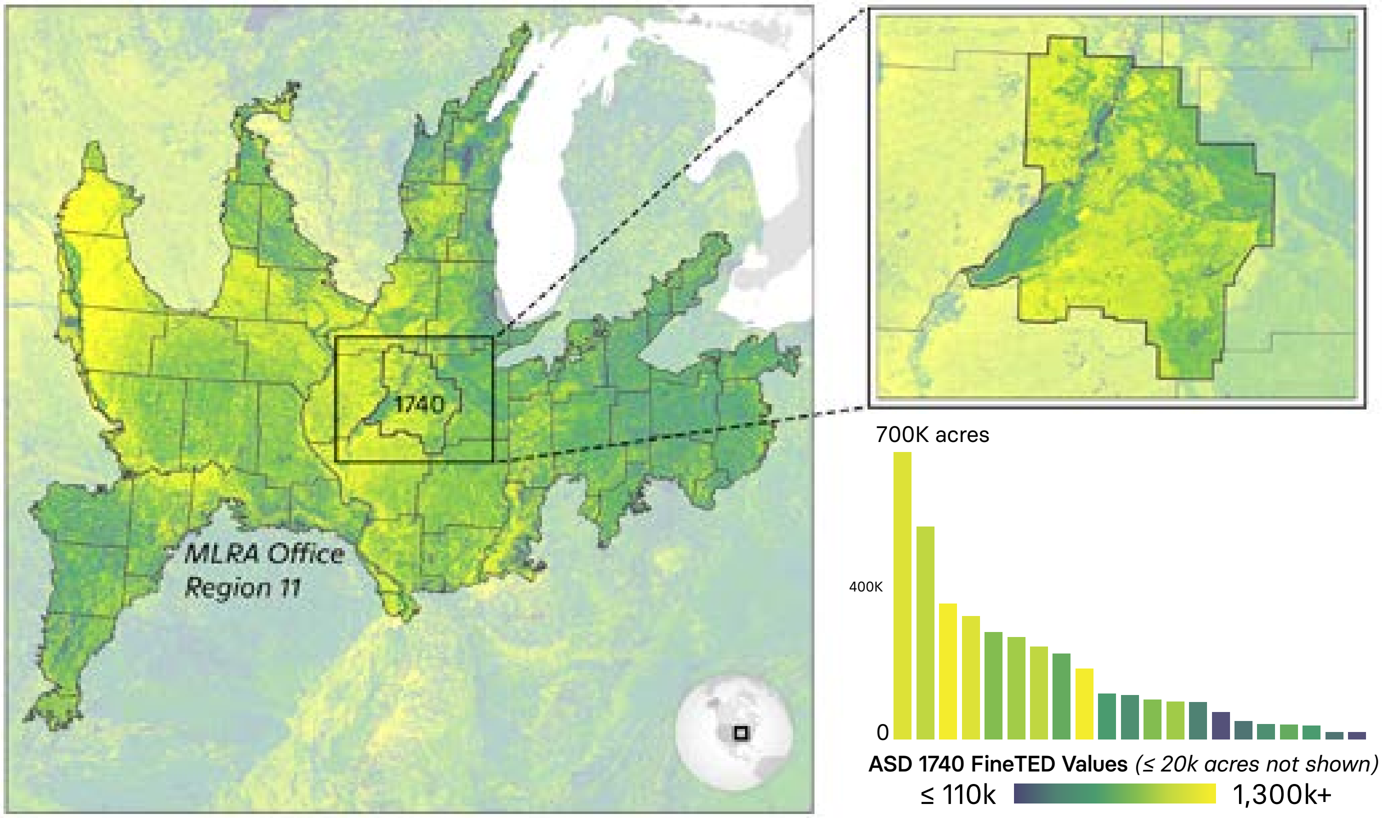
For instance, the technology extrapolation domain approach delineates regions via a robust spatial framework that identifies cropland cohorts with similar soils and climate where a comparable response to a technological intervention — broadly defined as tillage methods, crop varieties, fertilizer management, crop rotations and cover crop inclusion — would be expected (see Figure 2).[57] This spatial framework could also expand to include socio-economic circumstances — output and input prices, farm size, access to markets, credit and information.

Such an approach would achieve an appropriate scale to track annual variability in climate patterns, crop yields and broad-scale management adoption that would allow for more transparent and feasible accounting and assessment of leakage and additionality. Furthermore, an aggregated scale would mitigate against the risk of reversal by enabling the accumulation and management of a sufficiently large buffer account.

The USDA or another entity could facilitate the establishment and administration of an MRV program across technology extrapolation domain units (see Figure 2). Using an ensemble of process-based models[58,59] as a component of SOC MRV at large scales would also produce more accurate estimates of mean changes in SOC with reduced uncertainty versus accounting for changes in SOC on a project-by-project basis.[60,61]

USDA Agricultural Statistical Districts could also form jurisdictional boundaries in which the USDA or another entity would conduct larger-scale monitoring of the entire landscape, covering both carbon storage projects and the area without projects. This monitoring, analogous to jurisdictional approaches proposed for high-quality REDD+ tropical forest carbon credits[62] or for national emissions inventories,[63] would facilitate full carbon accounting, reducing issues associated with additionality, permanence and leakage and reduce the potential for double-counting.

**Figure 2: Example of aggregation at scale based upon tiered land classifications**




Technology extrapolation domains[64] (TEDs, shown in color), USDA Agricultural Statistical Districts (ASDs, delineated by black lines with district 1740 pictured), and USDA Major Land Resource Areas (MLRAs, darkened region) could provide a basis for a regional approach for SOC markets. TEDs identify areas of similar soils and climate where comparable responses to agricultural technologies and interventions would be expected. TEDs could provide an initial stratification layer over which project aggregators report on credit-generating activities to USDA ASDs. ASDs report TED-based activities to USDA MLRAs where project activities are aggregated by TEDs to eliminate bias. Using publicly available data through ASDs would enable more transparent accounting of market issues such as leakage, and calibrated remote sensing products could track the adoption of conservation practices such as reduced tillage and cover cropping to help account for additionality.

# Ensuring equity and environmental justice

Photo by: @jennrox85 via Twenty20

A long history of discriminatory policies and programs enacted by the USDA and other government entities have harmed farmers of color (e.g., discrimination in the processing of Black farm loan applications and higher rates of foreclosure among farmers of color).[65] It is essential that the potential financial benefits of carbon crediting programs are available to all communities, especially those who have been historically marginalized and often face barriers to participating in existing markets.

BCarbon includes explicit consideration of diversity, equity and inclusion within its crediting program. BCarbon plans to include strategies for supporting diversity, equity, inclusion and accessibility within its program such as outreach, internships, job training and creation, and fostering partnerships.

Furthermore, any crediting program designed to create offsets must explicitly address environmental justice concerns and be paired with strong regulatory protections for local air and water quality. The sale of offsets to high emitters allows industry to continue to emit carbon dioxide and other pollutants. Frontline communities, who are more likely to be people of color and low income, face higher exposure to these pollutants and suffer disproportionate health impacts.[66] Environmental justice concerns associated with offsets must be addressed and corrected for to ensure that any compliance regulations result in net environmental benefits both for the climate and frontline communities.

# Credit equivalency

Voluntary carbon markets are developing at a rapid pace. This momentum underscores the need for oversight by the USDA, or other such entity, to ensure that generated credits are equivalent and represent net environmental benefit.

Differences in the way protocols and carbon marketplaces estimate SOC and net GHG reductions, as well as the way they account for issues such as permanence and additionality of carbon sequestered, run the risk of creating credits that are not equivalent or even comparable. Furthermore, differences in the way credits are derived under different protocols and within different carbon marketplaces may result in developers and buyers focusing on securing the greatest number of credits for the least amount of investment. This could potentially push protocols with the highest standards out of the market. Inconsistent SOC credits would be especially problematic if they were used to meet U.S. NDCs or sold as offsets to sectors required to reduce emissions as part of a compliance market.

## BOX 5: CURRENT PROTOCOL ADOPTION AND EMERGING SOIL CARBON MARKETS AND CARBON PROGRAMS

Most of the protocols assessed have not yet been adopted; many of them have just recently been published (CAR SEP, Verra Methodology for Improved Agricultural Land Management, Gold Standard Soil Organic Carbon Framework Methodology and BCarbon).

Indigo Ag recently announced that it had secured commitments to sell verified carbon credits (through the use of Verra and CAR protocols) to several buyers, including Boston Consulting Group, Shopify, Barclays and JP Morgan Chase.

Nori Marketplace made its first major sale of verified credits in the fall of 2020. These credits, sold under the pilot phase of Nori's marketplace to Shopify, amount to 5,000 metric tons of carbon dioxide removal. Nori's protocol allows for backward-looking credits, through which farmers can accumulate credits for practices undertaken over the previous five years. This calls into question the premise of additionality for these pilot phase credits, and most other carbon programs do not allow for these "look-back" periods.

Microsoft announced its first round of purchased carbon credits from Regen Network, which includes 40,000 tons of sequestered SOC from a livestock operation in Australia, and has committed to buying credits developed under TruCarbon, a new carbon marketplace developed by Truterra, LLC.

Australia Emissions Reduction Fund has several registered projects under its Carbon Farming Initiative Methodology. Of the approximately 125 projects registered, the majority deal with pasture management (stocking rates and reseeding pasture). Only one project has received credits thus far. Alberta's Quantification Protocol for Conservation Cropping has delivered over 17 million tonnes of offsets since 2007.

The Government of Alberta requires industrial facilities exceeding 100,000 tonnes of carbon dioxide equivalents per year to report and reduce their emissions to established targets. Emission offsets regulated by Alberta's Quantification Protocol are an option for these large emitters to meet their reduction requirements. This protocol is practice-based and applies to any farm using reduced or no-tillage where sufficient records are available to justify the emissions reductions being claimed. This protocol is set to expire on December 31, 2021, due to the end of a 10-year crediting period, after which no additional credits will be issued.

Other protocols such as Verra's Soil Carbon Quantification Methodology (VM0021) have not seen any adoption since its publication in 2012. The methodology relies on Verra's Estimation of Stocks in the Soil Carbon Pool (VMD0021), which has extremely intensive sampling requirements that present a significant barrier to adoption.

In addition to the protocols covered in this report, announced SOC crediting programs for both scope one and scope three emission reductions are currently enrolling farmers but do not yet have published protocols that are publicly available. With some of these programs, it is unclear if they will adopt a published protocol such as CAR SEP or VM0042 or develop their own. It will be critical to track the different approaches these programs take on MRV (e.g., hybrid approaches, remote sensing and process-model approaches) and their requirements for meeting additionality, permanence and accounting for potential reversals. Programs announced as of April 2021 include Soil and Water Outcomes Fund, CIBO, TruCarbon, Bayer Carbon Initiative, Ecosystem Services Market Consortium, Nutrien, Gradable Carbon and Corteva's Carbon and Ecosystem Services portfolio.

# Recommendations

Paying farmers to sequester SOC remains an uncertain approach to climate change mitigation due to reversal risk and the uncertainties of accurately detecting carbon stock change over time. Current research and MRV advances will help address these challenges by providing the evidence needed for outcomes to match expectations.

For SOC sequestration to become an important mitigation strategy worthy of government and private sector investment, a credible, cost-effective and consistent MRV system is essential for building trust and confidence in the credits generated. In the meantime, we believe only avoided land conversion and direct emission reductions — for example, reduced nitrous oxide emissions via improved nutrient management and reduced carbon dioxide emissions via reduced tractor use — that are consistently accounted for and can be verified should result in credits that might count toward NDCs or emission offsets.

Commitments by food and agriculture companies to reduce scope three emissions from their supply chains can add value by accelerating the adoption of agricultural practices that can have benefits beyond SOC storage, such as increased resilience to climate change impacts.[67] Such adoption can also support continued research, pilot projects and advances in MRV that are needed to address the current challenges and uncertainties associated with carbon credits by providing the evidence needed for outcomes to match expectations.

Establishing a USDA-led carbon bank or other federal system would complement actions by the private sector and could help mitigate uncertainties associated with net SOC sequestration by assuming some of the risk upfront. For instance, the USDA could support research and technological advances while maintaining accounting of credits during an initial development phase.

The creation of a national soil monitoring program analogous to the U.S. Forest Service's Forest Inventory and Analysis would facilitate consistent baselines and accounting methodology. The system could set a standard approach for permanence (e.g., 100 years), additionality (e.g., setting uniform baselines for technology extrapolation domain units) and accounting for net GHGs. The USDA could pilot a unified approach to ensure that the technology extrapolated domain-based scale enables equitable inclusion of diverse farm operations and that the scale of aggregation allows for reduced uncertainty and greater confidence in generated credits.

Additionally, federal policymakers, protocol and project developers, food and agriculture companies, and researchers should prioritize the following actions to help build confidence and reduce uncertainty with respect to agricultural SOC credits:

- Validate and compare the net GHG reductions estimated by different MRV protocols and the associated uncertainty against measured changes at benchmark sites.

- Determine the appropriate scale of aggregation and level of buffer accounting — based on agroecological and biophysically defined regions (e.g., technology extrapolation domains[68]) and socio-economic attributes — to best account for additionality and leakage, reduce risks associated with reversals and support participation of diverse farm operations within any crediting program.

- Evaluate whether a multi-model ensemble approach for each aggregated region can be used to reduce structural and parameter uncertainties in individual models.

- Create open-access datasets with harmonized high-quality data for model calibration and benchmarking efforts across agroecological zones (see Box 4). A network of benchmark sites can support continual model improvement in an open, collaborative fashion.

- Develop cost-effective approaches to MRV using emerging technologies and user-friendly technology (e.g., a web-based applications), such as quantitatively backed stratification approaches to ensure samples are collected in a rigorous way that appropriately captures landscape heterogeneity.

- Identify — in the U.S. and globally — characteristics of agricultural soils with the highest capacity to store carbon over decadal time frames. Voluntary and regulatory markets could then focus on those areas (regions or landforms) where real SOC increases are most readily realizable.

These actions can take place over both immediate and longer timescales and will improve confidence, increase scalability and help ensure net environmental benefits for the development of scope one carbon credits.

# Appendix A

TABLE A-1:

## Additionality, permanence, reversals and leakage requirements for synthesized protocols

| PROTOCOL | ADDITIONALITY REQUIREMENT | PERMANENCE PERIOD | REVERSALS | LEAKAGE | CONSIDERATION OF OTHER GHGS (E.G., NITROUS OXIDE AND METHANE) |
|---|---|---|---|---|---|
| Climate Action Reserve Soil Enrichment Protocol v 1.0 | Yes, performance standard test and legal requirement test | Yes, commitment of 100 years or tonne-year accounting where credits are issued as a proportion of 100-year permanence period | A percentage of credits go to a buffer pool | Yes, accounts for leakage related to displacement of livestock and sustained reductions in crop yields | Yes, net emissions accounted for through use of modeling or emissions factors |
| Verra VM0042 Methodology for Improved Agricultural Land Management, v 1.0[1] | Yes, identification of barriers preventing project activities and performance standard test | Yes, 30 years, with risk of non-permanence calculated using the VCS AFOLU Non-Permanence Risk Tool | Yes, a percentage of credits go to a buffer pool | Yes, accounts for application of manure from outside project area, sustained reductions in crop yields and livestock displacement | Yes, net emissions accounted for through use of modeling or emissions factors |
| Verra VM0017 Adoption of Sustainable Land Management (SALM), v 1.0[1] | Yes, must use additionality tool for Clean Development Mechanism project activities | Yes, 30 years, with risk of non-permanence calculated using the VCS AFOLU Non-Permanence Risk Tool | Yes, a percentage of credits go to a buffer pool | Yes, accounts for use of fuel from non-renewable sources due to decrease in use of manure that may be transferred to fields through project activities | Yes, net emissions accounted for using emissions factors |
| Verra VM0021 Soil Carbon Quantification Methodology, v 1.0[2] | Yes, must use additionality tool for Clean Development Mechanism project activities | Yes, 30 years, with risk of non-permanence calculated using the VCS AFOLU Non-Permanence Risk Tool | Yes, a percentage of credits go to a buffer pool | Yes, accounts of livestock displacement and sustained reductions in crop yields | Yes, emissions factors applied if project activities result in emissions >5% of baseline |
| Nori Croplands Methodology, v 1.1 | Yes, project activities must show improvement in carbon sequestration over baseline scenario | 10 years | Yes, restricted tokens are used to account for any deliberate reversals | Verification will establish if SOC stock gains result in losses outside of project boundary | No |
| Gold Standard Soil Organic Carbon Framework Methodology v 1.0 | Yes, performance standard test and legal requirement test | Permanence required within crediting period (depending on SOC Activity Module, 5-20 years) | Yes, a percentage of credits go to a buffer pool | Yes, accounts for shifting crop production | Yes, modeling or emissions factors applied if project activities result in emissions >5% of baseline |
| Carbon Credits (Carbon Farming Initiative — Measurement of Soil Carbon Sequestration in Agricultural Systems) Methodology Determination | Yes, a "newness" test that requires at least one new management activity | 100 or 25 years; if projects opt for 25, then 20% of credits will be deducted | Yes, a percentage of credits go to a buffer pool | Yes, accounts for application of amendments outside of project area | Yes, emissions factors are used if project emissions are greater than those of baseline |
| Carbon Credits (Carbon Farming Initiative — Estimating Sequestration of Carbon in Soil Using Default Values) Methodology Determination | Yes, a "newness" test that requires at least one new management activity and will result in expected changes | 100 or 25 years; if projects opt for 25, then 20% of credits will be deducted | Yes, a discount rate on sequestration is applied if a "depletion event" has taken place | Yes, accounts for leakage resulting from new irrigation (if using new water access entitlement or irrigation right) | Yes, net abatement is calculated through the FullCAM model |

**TABLE A-1 continued:**

## Additionality, permanence, reversals and leakage requirements for synthesized protocols

| | | | | | |
|---|---|---|---|---|---|
| Alberta Quantification Protocol for Conservation Cropping, v 1.0 | Yes, eligible project must be new and additional to business as usual; sequestration coefficient discounted according to observed rate of increase in adoption of no-till | 20 years | Yes, each offset is discounted by a percentage specific to the region containing project | Based on ISO 14064:2 — activity shifts deemed minimal | Yes, regionally based emissions factors built into sequestration coefficients |
| FAO GSOC MRV Protocol | Yes, project must show improvement over baseline in sequestration by performing a 20-year SOC simulation | Projects are planned for a 4-year duration and can be renewed for another 4 years. | Yes, a 5% risk of reversal discount will be applied to sequestration projects | Potential sources of leakage defined during the initial project assessment | Yes, net emissions accounted for through use of modeling or emissions factors |
| BCarbon | Issued credits will be for carbon added to the ground after initiation of testing | 10 years, which is renewable each subsequent year when new credits are issued | 10% of credits go to a buffer pool | Potential sources of leakage will be assessed by life cycle assessment[3] | No |
| Regen Network Grasslands Protocol | Yes, eligible project must implement practices new and additional to business as usual | 25 years | Yes, a percentage of credits go to a buffer pool | Potential sources of leakage tracked over time | Yes, net emissions accounted for using IPCC or relevant national/state/regional factors |

[1] VM0042 is a hybrid sampling-modeling approach that can be applied internationally; VM0017 is a model-only approach that is targeted more specifically for small-holder agriculture.

[2] VM0021 is a hybrid sampling-modeling approach that has not been adopted likely due to its strict soil sampling requirements as outlined in VMD0021 (see Table 3).

[3] This life cycle approach is currently under development and will stipulate that any increase in the life cycle emissions must be deducted. Decreased emissions will not be credited.

TABLE A-2:

## Soil carbon estimation and sampling methodologies

| PROTOCOL ASSESSED | APPROACH (MODEL, SAMPLING, HYBRID) | REQUIRED MODEL? | BASELINE VALIDATION (DYNAMIC VS. STATIC) | STRATIFICATION | MINIMUM NUMBER OF SAMPLES PER STRATA? | FREQUENCY OF SAMPLING | ALLOWABLE UNCERTAINTY |
|---|---|---|---|---|---|---|---|
| Climate Action Reserve Soil Enrichment Protocol v 1.0 | Hybrid | No, but must meet minimum requirements (publicly available, peer reviewed) | Dynamic performance baseline calibrated with sampling | Required | 3 | Every 5 years | 15% |
| Verra VM0042 Methodology for Improved Agricultural Land Management, v 1.0 | Hybrid | No, but must meet minimum requirements (publicly available, peer reviewed) | Dynamic performance baseline calibrated with sampling | Recommended | Not specified | Every 5 years | 15% |
| Verra VM0021 Soil Carbon Quantification Methodology, v 1.0[1] | Hybrid | Yes, DNDC | Static established by sampling | Required, minimum of 1 | Not specified | At least every 5 years | 10% |
| Verra VM0017 Adoption of Sustainable Land Management (SALM), v 1.0 | Model | Recommend RothC | Static baseline | Recommended | N/A | N/A | 15% |
| Nori Croplands Methodology, v 1.1 | Model | GGIT | Dynamic performance baseline | Not specified | N/A | N/A | Depends |
| Gold Standard Soil Organic Carbon Framework Methodology v 1.0[2] | Sampling or hybrid[3] | No, but must be a peer reviewed model | Either performance or static depending on accounting approach | Yes | Not specified | Every 5 years | 20% |
| Carbon Credits (Carbon Farming Initiative — Measurement of Soil Carbon Sequestration in Agricultural Systems) Methodology Determination | Sampling | NA | Static established by sampling | Required, minimum of 3 | 3 | At least every 5 years | Probability of exceedance = 60% |
| Carbon Credits (Carbon Farming Initiative — Estimating Sequestration of Carbon in Soil Using Default Values) Methodology Determination | Model | Yes, FullCAM model | Static performance baseline | N/A | N/A | N/A | Uncertainty associated with activity data, and the model was determined using a Monte Carlo analysis in conjunction with the IPCC approach one propagation of error method |

TABLE A-2 continued:

## Soil carbon estimation and sampling methodologies

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| FAO GSOC MRV Protocol | Hybrid | No, but evidence must be provided (publications, local research studies) demonstrating the use of the model is appropriate for the agroecological zone where the project is located | Dynamic performance baseline calibrated with sampling | Required, minimum of 3 | Minimum of 3 composite samples | Every 4 years | Not explicitly stated |
| Alberta Quantification Protocol for Conservation Cropping, v 1.0 | Practice-based | Uses an empirical modeling approach specific to project area regions | Performance standard | N/A | N/A | N/A | Uncertainty is accounted for in the estimation of sequestration coefficients |
| BCarbon | Hybrid | No, each model used will be reviewed by project team | Static baseline established by sampling | Required | None specified | Every 5 years | 10% |
| Regen Network Grasslands Protocol | Remote sensing | No | Static baseline established by sampling | Recommended | Soil sampling protocol provides a minimum number of required samples per 1000 hectares | At least every 5 years | 20% |

**PROTOCOLS/METHODOLOGIES DEVELOPED FOR SOIL SAMPLING**

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Verra VMD0021 Estimation of Stocks in the Soil Carbon Pool, v 1.0 (this protocol is specific to the soil sampling requirements for VM0021) | Sampling | No | Static established by sampling | Required, minimum of 1 | Not specified | Not addressed (as this is a methodology to support other registries) | Not addressed (as this is a methodology to support other registries) |
| ICRAF A Protocol for Modeling, Measurement and Monitoring Soil Carbon Stocks in Agricultural Landscapes, version 1.1 | Sampling | N/A | Static established by sampling | Recommended | Not specified | Not addressed (as this is a methodology to support other registries) | Not addressed (as this is a methodology to support other registries) |

[1] The sampling requirements for VM0021 are outlined in the supporting module, VMD0021, Verra VMD0021 Estimation of Stocks in the Soil Carbon Pool, v1.0.

[2] Sampling or modeling protocols that can be used to support monitoring requirements for other registries (e.g., VMD0021 is an approved sampling protocol for Gold Standard's Soil Organic Carbon Framework Methodology).

[3] There are three approaches available for quantification of emission reductions through this protocol: (1) Approach 1: On-site measurements to directly document baseline and project SOC stocks; (2) Approach 2: datasets, parameters, models from peer-reviewed pubs to estimate baseline and project SOC stocks; (3) Approach 3: default factors to estimate SOC changes (IPCC). For approaches 2 and 3, direct sampling is required for validation.

# Appendix B

To download a matrix with more specific details on measurement approaches and structural considerations for each synthesized protocol, please visit edf.org/SOC-protocol-matrix.

# Notes

[1] The nine crediting organizations (representing the 12 MRV protocols) provided review and feedback of our interpretation for their protocols.

[2] A number of other land-based agricultural protocols have been developed over the last several years that focus on avoided conversion, nitrogen management and sustainable grassland management. The protocols assessed in this report focus primarily on net emission reductions from cropland management approaches that target carbon sequestration. We included one protocol that focuses exclusively on grassland management from Regen Network because they are selling credits on the market, and their Grasslands Methodology protocol depends heavily on remote sensing for SOC quantification.

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