Version 2

BCarbon Soil Carbon Protocol

Issued: October 2022

TABLE OF CONTENTS

1.0 OVERVIEW

This document defines the specifications for measuring the accumulation of soil organic carbon (SOC) in soil over a true-up period with adequate accuracy to support certification of soil carbon sequestration credits by BCarbon. Parties using this protocol will need to demonstrate compliance with these procedures. This protocol defines a 6-step process, addressing site selection and stratification, quantification of the accrued carbon mass, and interim credit estimates. Equivalent methods not included in this standard may be applied subject to approval by BCarbon.

BCarbon would like to extend a special thank you and its sincere gratitude to the team at GSI Environmental Inc. as well as the Soil Metrics Subcommittee for the original development of this protocol.

2.0 OBJECTIVES, APPLICABILITY, AND SCOPE OF SOIL CARBON PROTOCOL

2.1 ***Objectives:*** This protocol defines methods for quantifying the increase in soil organic carbon over time on a property with the necessary statistical reliability to support the issuance and sale of carbon credits.

2.2 ***Definitions:*** For this protocol, belowground carbon is defined as the sum of:

- *Soil organic carbon (SOC):* The organic carbon mass, as determined by acceptable field and/or laboratory methods on properly collected samples, for the fraction of the soil sample that passes through a 2 mm sieve; and
- Soil inorganic carbon (e.g., caliche, calcium carbonate, or dolomite) is not credited under the BCarbon protocol.

2.3 ***Applicability:*** This protocol may be applied to any land management practice that enhances and maintains below-ground carbon in a manner that preserves or improves soil health; i.e., the capacity of the soil environment to serve as a sustaining ecosystem for the benefit of plants, animals, and humans.

2.4 ***Scope:*** The specifications presented are directed to a project or activity for soil organic carbon accrual pertaining to a specified land area, depth interval, and length of time or *true-up period (estimated 5 years between measurements)*. The protocol identifies a stepwise process that includes measurement of the soil organic carbon mass at the beginning of the project period and measurement of the net increase in soil organic carbon mass at the end of the project period, while accommodating the issuance of interim soil carbon credits prior to the true-up period.

The Standard Procedures provided identify acceptable methods for sampling, testing, monitoring, and statistical analysis. It is expected that other equivalent, scientifically sound methods may be or become available. Use of these alternative methods is subject to the advance review and approval by BCarbon. If alternative methods are employed, the appropriateness and reliability of these alternative methods must be documented as part of the project record.

2.5 ***Limitations:*** This protocol is directed to soil organic carbon measurements only and does not encompass the evaluation of above-ground carbon accrual (e.g., trees, shrubs, or other biomass) associated with land management practices. Quantitative analysis of the potential net increase in net greenhouse gas (GHG) emissions associated with a change in land management practices is not required.

2.6 ***Recommended Methods for Sampling, Testing, Modeling, and Quantification of Soil Organic Carbon:*** This document provides Standard Procedures A through E regarding acceptable methods for definition of sub-areas and group projects (Standard Procedure A), recommended procedures for sample collection and laboratory testing (Standard Procedure B), methods for forecasting and monitoring carbon accrual (Standard Procedure C), and statistical analysis of data to estimate the net accrual of SOC over the project period (Standard Procedure D). Standard Procedure E provides the required documentation of project procedures and results.

3.0 PROCESS FOR QUANTIFICATION OF SOIL ORGANIC CARBON ACCRUAL

This protocol prescribes a 6-step process, based upon measurement of the initial soil organic carbon content at the start of the project, a second round of measurements at the end of the true-up period, and a statistical analysis of the net carbon mass accrued over that length of time. Figure 1 provides an illustration of these process steps. Performance criteria for each step of this process are provided below.

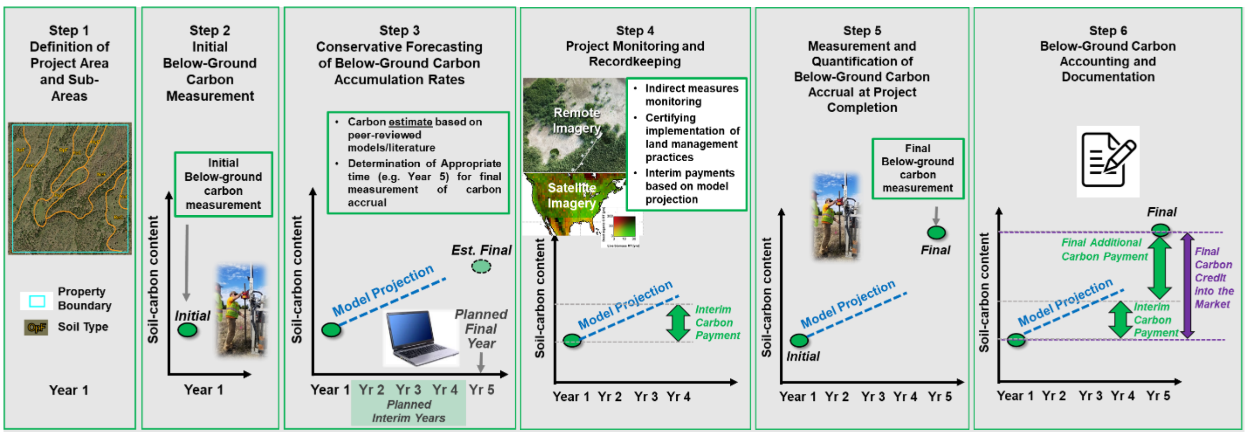


Figure 1: Illustration of 6-Step Process for Quantification of Soil Organic Carbon Accrual Over Time (Note that the application for interim credits (steps 3 and 4) is optional and issuance is at the discretion of BCarbon.)

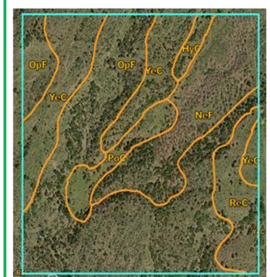
Step 1: Stratification of Project Area and Sub-Areas

Overview and Objectives: Measuring changes in soil organic carbon content is challenging due to natural variability of soils and soil carbon. In order to detect a real change in SOC, one must have a sufficient number of samples to ensure sufficient power to detect an effect.

The power to detect a change is based on the natural variability of measured values and the magnitude of what would be considered a meaningful change. The more variable the soils are or the smaller the magnitude of change, the larger sample size needs to be to detect a change.

Stratification is one important strategy to reduce background SOC variability as well as contrasting responses to environmental or management responses. Stratification is a process where the site is divided into sub-areas based on similar soil characteristics such as texture, minerology, aspect, and overlying vegetation. Proper stratification may reduce the number of samples necessary to characterize baseline carbon content with the necessary accuracy and improve the reliability of the measurement of the change in carbon content over time.

Step 1
Definition of Project Area and Sub-Areas



Property Boundary

Soil Type

Year 1

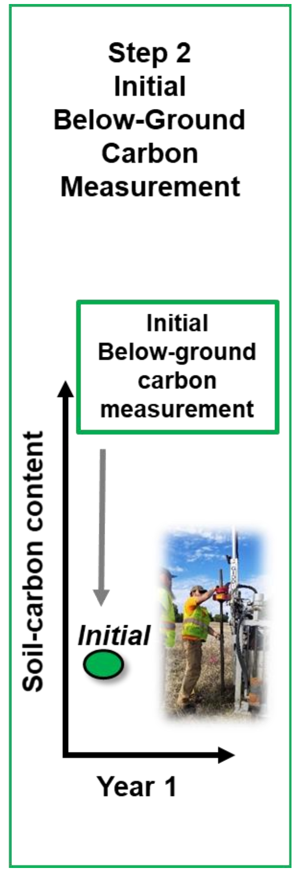
Definition of Project Area, Depth, and Time Period: Each soil organic carbon project shall be defined based on an identified land area, soil depth interval, and a specified timeframe for the carbon accrual period (beginning and ending dates), hereinafter referred to as the "project period," which is defined at the discretion of the user. The dimensions and boundary lines of the project area shall be defined, the land area calculated, a depth of accrual specified, and the corresponding volume of soil recorded. The depth of the soil zone within which significant carbon accrual will occur depends on the nature of the soils, the selected land management activity, and other factors and should be determined on a site-specific basis. Commonly selected depths range from 30 to 100 cm.). To facilitate the comparison of carbon content at the beginning and end of the project period, the soil volume must also be expressed as an equivalent mass of soil, using measurements of soil density collected in Step 2 of this process.

Sub-Areas of Comparable Soil Composition: The defined project area must be stratified to define sub-areas within which the key parameters related to carbon accrual rates are relatively uniform. Such parameters include soil texture; vegetative structure, density, and diversity; drainage, current land use; and landform. The properties of these parameters across the project area shall be determined based upon published information (e.g., the USDA soil classification system or equivalent), physical inspection of the soils, landowner knowledge, and other reliable information sources. Commonly published sources such as USDA soil classifications and maps will prove useful, but alone may not provide sufficient site-specific information to define sub-areas. Guidelines for definition of sub-areas are provided in Standard Procedure A.

Criteria for Group Projects: Owners of geographically co-located properties may combine their land areas as a "group project" under this protocol if the areas share comparable soil and land characteristics and are subject to consistent land management practices. The combination of such like areas may potentially reduce the number of soil samples per unit land area that are necessary to define the soil organic carbon content. Group projects require advance review and approval by BCarbon based upon demonstration that the proposed combined areas share consistent properties of key stratifying parameters and will be subject to the same sampling, testing, monitoring protocols, as well as consistent land management practices. Performance criteria for group projects are provided in Standard Procedure A. It is important to note that, under Steps 2 and 5 below, group projects will require sample locations distributed across the full group project area to obtain a representative measure of soil organic carbon.

Step 2: Initial Belowground Carbon Measurement

The initial soil organic carbon content of the project soils shall be measured by means of direct sampling and testing to determine the mean soil organic carbon content of the soils in each sub-area, applying the performance criteria outlined in Standard Procedure B. For sequential true-up period measurements conducted on the same property, the ending sampling program for the preceding project period will constitute the beginning sampling program for the subsequent true-up period.



The number of soil samples collected and analyzed shall be adequate to quantify the current carbon content and later determine the net gain soil organic carbon over the true-up period to an acceptable degree of statistical reliability. In general, the greater the number of samples, the greater the statistical power to detect a change in SOC . The statistical methods to be applied for this purpose are specified in Standard Procedure D.

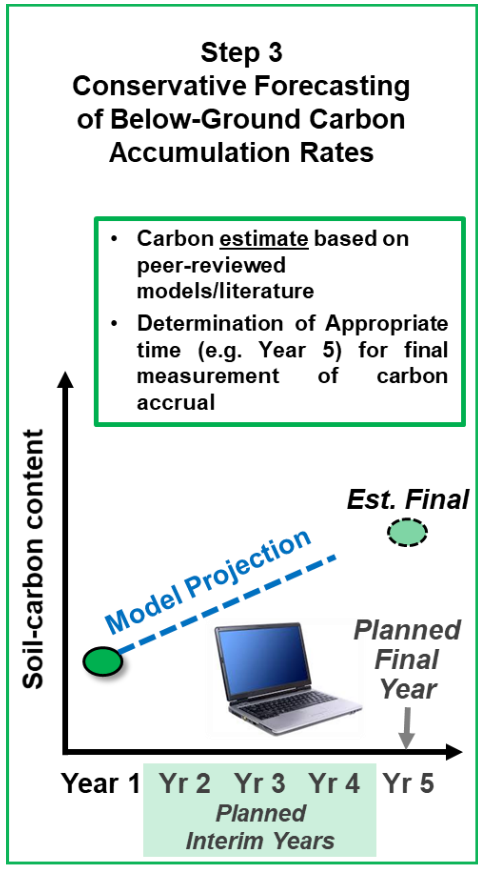
In addition, measurement and documentation of other soil and land characteristics, such as soil texture, vegetative density and diversity, and other relevant parameters are recommended to facilitate effective monitoring of the carbon accrual effort over time (see Standard Procedure C).

Records of sample locations, sampling methods, field and laboratory testing, test results, and statistical analyses shall be maintained to support certification of initial SOC content by BCarbon and included in a final project report (see Standard Procedure E).

Step 3: Forecasting of Soil Organic Carbon Accrual Rates if applying for interim credits

This step is for projects considering applying for interim credits prior to the true-up period.

Forecasting of SOC accrual over the true-up period is a recommended but not mandatory step of this protocol. Advance estimation of carbon accrual rates may provide the benefits of i) confirming that an adequate number and locations of samples have been collected to quantify the initial and final soil organic carbon content with the necessary statistical confidence, ii) accommodating issuance of interim soil carbon credits during the true-up period, and iii) selecting or adjusting land management practices to optimize carbon accrual. In some cases, the forecasting efforts may indicate that the project will not achieve carbon accrual goals without significant modification.

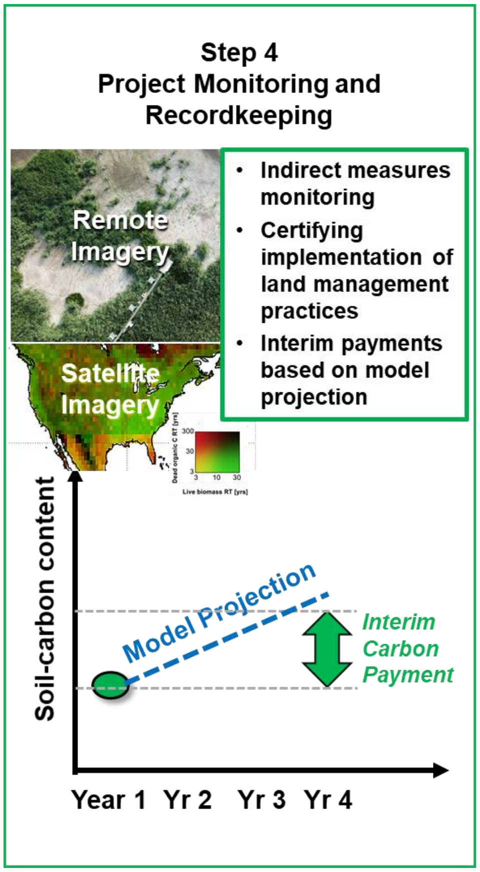


This protocol provides specifications for two optional methods of forecasting or estimating carbon accrual rates in the project area: i) modeling of the rate of carbon accrual rates using analytical or numerical models of soil carbon dynamics, and ii) estimation of carbon accrual over time based on empirical relationships or checklists that rely on performance indicators, such as the vegetative density, soil moisture content, and other measures of soil health. The applicability of the selected methodology to the project conditions and the appropriateness of the input parameters must be documented based on site-specific measurements and observations as well as professional judgment.

If either of these forecasting options are to be used to justify issuance of interim carbon credits, care must be applied to avoid over-estimation of carbon accrual during the project period. For this purpose, the uncertainty in the estimation method must be quantified and documented, and the method applied to provide a conservative (low) estimate of the accrued carbon content at the end of the project period.

Specifications for forecasting carbon accrual rates are provided in Standard Procedure C.

Step 4: Project Record-Keeping, Monitoring, and Eligibility for Interim Carbon Sales

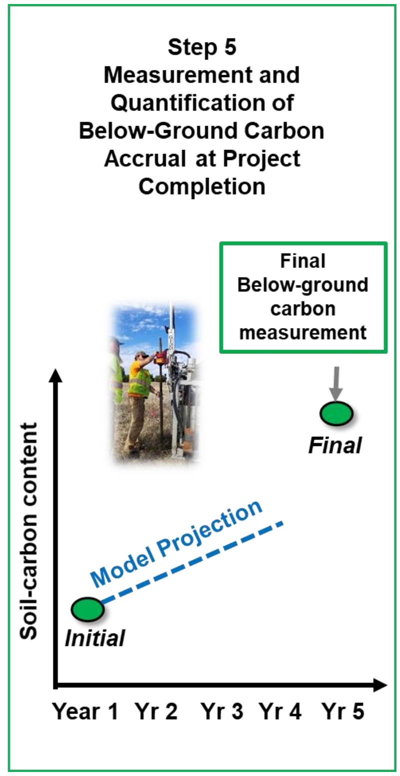


Project Monitoring and Record-Keeping: Each year of the true-up period, the user must certify in writing that appropriate land management practices remain in effect in the full project area to increase soil organic carbon content.

In addition, it is recommended but not mandatory that indirect measures of soil organic carbon accrual be collected and recorded on a periodic basis (*e.g.*, annually) to support certification of carbon accrual. These data serve to monitor progress toward achieving the SOC content anticipated at the end of the true-up period at less cost than direct soil sampling and testing. Such indirect measures of carbon accrual include remote sensing techniques, observations of vegetative cover and density, monitoring of soil color and moisture. Recommendations for these indirect monitoring methods are provided in Standard Procedure C.

Eligibility for Issuance of Interim Carbon Credits: Subject to demonstration that appropriate land management practices remain in effect to increase SOC, the incremental increase in belowground carbon estimated to have been achieved prior to the project end date can be used to support issuance of interim carbon credits. Alternatively, direct sampling and testing can be conducted at any time during the project in accordance with Step 5 and used to quantify the net increase in soil organic carbon with the necessary statistical confidence. Issuance of interim carbon credits will require review and approval by BCarbon, subject to the criteria set forth in Standard Procedure C.

Step 5: Measurement and Quantification of Soil Organic Carbon Accrual at the End of the Project Period

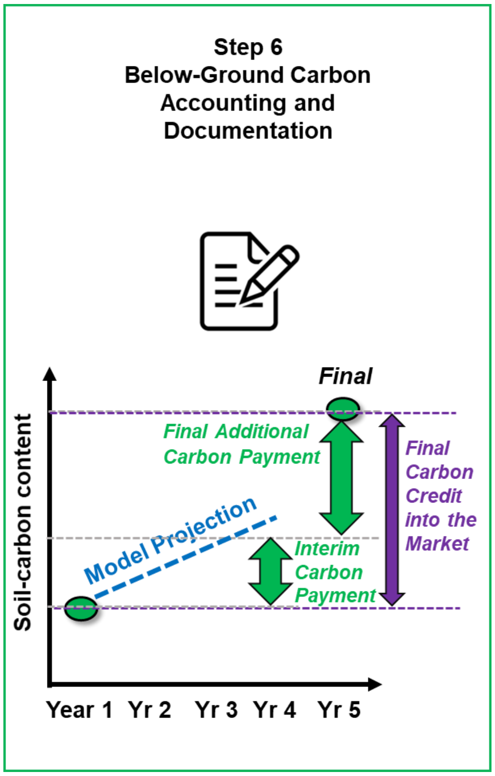


The end date of the true-up period is established at the discretion of the user and may be modified at any time. At this end date, samples shall be collected and analyzed from the project sub-areas using the same methods as applied in Step 2 above and in the same month as the prior sampling program to minimize variability introduced by changes in methodology or seasonality. Sampling data shall be evaluated to quantify the soil organic carbon content in the project area at the end date. The measured SOC content at the beginning and end of the project period shall then be compared to quantify the net increase in belowground carbon content in the project area, using the statistical procedures described in Standard Procedure D or other equivalent, scientifically accepted methods subject to the approval of BCarbon.

Statistical evaluation is necessary to determine the uncertainty of the estimation of the net increase in soil organic carbon content and to provide a reliable value for carbon credits. This protocol provides two methods for quantifying the net change in SOC over the true-up period: i) estimation of the difference in the beginning and ending mean soil organic carbon content of each sub-area by subtracting the beginning mean SOC content, estimated within a specified margin of error, from the ending mean SOC content, estimated within that same margin of error, or ii) estimation of the lower confidence limit of the "difference between means" for the beginning and ending sample populations.

Step 6: Soil Organic Carbon Accounting and Documentation

To support certification of soil carbon sequestration credits, the user must provide a report to BCarbon that describes the carbon project and documents the basis for estimation of the net increase in SOC in the project area over the true-up period. The report shall address the procedures and results of Steps 1 through 5, including definition of the project area and sub-areas, land management practices, monitoring data, initial and final soil testing results, and statistical analyses. The net additional SOC mass at completion of the ending measurement (Step 5) will be eligible for carbon credits, minus any carbon mass for which interim credits were issued during the project period. Upon completion of the project period, if the project will be extended to accrue additional carbon, the ending sampling program will be considered the beginning sampling program for the subsequent project period. Detailed guidelines in the belowground carbon accounting and documentation are included in Standard Procedure E.



The user of this protocol is directed to the attached Standard Procedures A – E for specifications for each step of the process. The project report shall document that these procedures or equivalent methods for measurement, monitoring, and quantification of soil organic carbon accrual have been applied for the purpose of the project.

STANDARD PROCEDURE A: STRATIFICATION REQUIREMENTS FOR SAMPLING IN PROJECT AREA, SUB-AREAS, AND GROUP PROJECTS

A.1 Overview and Objectives

This Standard Procedure provides specifications for dividing the project area into sub-areas of uniform characteristics in which sampling and analysis can be conducted to quantify the net change in belowground carbon mass over time, with sufficient accuracy to support the issuance of soil carbon credits.

The project area must be stratified, a process in which the site is divided into sub-areas in which the soil characteristics are sufficiently similar to minimize the natural variability of baseline SOC content in each individual sub-area. Proper stratification may reduce the number of samples necessary to characterize baseline and future carbon levels with the necessary accuracy and improve the reliability of the measurement of the change in carbon content over time.

The procedures described may be applied to a single property or to a combination of separate properties that qualify as a "group project," based upon a demonstration that the properties can meet the same stratification criteria as required for a single property and will enforce consistent land management practices on each property.

A.2 Definition and Stratification of the Project Area

A.2.1 Identification of Project Location and Soil Depth Profile

The area and depth of the soil zone for which carbon accrual will be measured over time shall be defined in terms of a specified depth interval belowground surface and the dimensions and boundary lines of the project area. The project area shall be defined by means of a GPS survey and recorded on a scaled GIS map to provide an accurate estimate of the total surface area to be subject to the carbon accrual effort. It is understood that the full extent of the defined project area will be subject to the land management activities for carbon accrual. Consequently, if some portion of the defined area will not be actively used for carbon accrual (e.g., an internal drainage way, roadways, etc., that is not accessible or amenable to the land management activity), such portion or portions of the project area shall be excluded from the project area to be used for calculation of carbon accrual.

The depth of the soil zone in which significant carbon accrual may occur depends on the nature of the soils, the selected land management activity, and other factors. Commonly selected depths range from 30 to 100 cm. The depth interval selected is at the discretion of the user, provided that the same depth interval is applied in the beginning and ending sampling programs in each sub-area. It is intended that the full extent of the defined project area has soil at least as deep as the specific depth (e.g., 0-30 cm) chosen.

A.2.2 Stratification of the Project Area into Sub-Areas

The defined project area must be evaluated to define sub-areas using such factors and characteristics as soil type, vegetative density, land slope, aspect, and drainage features, topography, and current and past land management practices. If these parameters vary in the proposed project area, the project area shall be divided or "stratified" into sub-areas of similar characteristics. These sub-areas may be contiguous land areas or may incorporate discrete tracts with similar characteristics in the project area. Sampling and testing must be conducted in each sub-area to quantify SOC in that sub-area.

Different soil types (e.g., sand vs. clay) on the same property may differ in terms of their initial carbon content, the spatial variability of this carbon content, and the rate at which additional carbon can be accumulated under a given land management scenario. The variability of SOC will commonly be greater between areas of different soil types than within an area of a single soil type. Further dividing the project area by differences in vegetative density, topography, and current and past land management practices further improves the efficiency and reliability of the sampling program. In addition, accurate estimation of the SOC requires that areas of significant differences in carbon mass be segregated so that low-carbon sub-areas are not mixed with high-carbon sub-areas, resulting in a significant over- or under-estimation of SOC.

A.2.3 Relevant Information and Considerations for Site Stratification

Information on the soil type, topography, and vegetative density of a given property may be available in various published resources. This information can be used to stratify the project area into sub-areas of similar soil, vegetative, and current and historical land management conditions. Available published information may include soil surveys, ecological classifications, and aerial images, as described below.

A.2.3.1 Stratification by Soil Texture and/or Type

Stratification of the project area starts with the identification of soil and landscape conditions. For many areas in the US, soil surveys (such as USDA National Resources Conservation Service (NRCS)) and similar publications provide information about the soils in a specified county or area of interest, including soil descriptions and their location, along with information on their physical and chemical characteristics, soil health properties, and susceptibility to erosion. Soils can be classified based on parent material, time, topography, climate, and native vegetation. On this basis, soil maps have been developed separating the landscape into landforms or landform segments with similar use and management requirements. USDA NRCS soil survey maps and other similar publications delineate distinct “soil map units,” which are areas of a predominant taxonomic soil classification with a specific range of soil parameters. These parameters include the soil unit descriptions, as well as its grain size composition, drainage properties, organic carbon content, and other properties that are important to its suitability for various land uses.

Publicly available sources of soil survey maps and similar information include:

- Web Soil Survey - *online interactive map* (Soil Survey Staff [a])
- Soil Data Viewer or gNASTGO - *Esri ArcMap extension or tool* (Soil Survey Staff [b] & [c])
- SoilWeb Apps - *online interactive maps and Google Earth application* (California Soil Resource lab)

These maps utilize the same USDA NRCS databases but provide various ways to access the data. Maps can be overlain on the project area to develop a preliminary definition of sub-areas of similar soil units. Published soil maps are often based upon interpolations among a limited number of regional sampling points and, for a given property, the boundary lines among soil groups may not be sufficiently reliable for use in stratification. Consequently, physical inspection of the property is commonly necessary to confirm the accuracy of the soil unit descriptions and boundaries, with sub-areas then adjusted as necessary to reflect actual ground conditions. Such inspection shall entail field classification of soils at multiple locations throughout each preliminarily defined sub-area to confirm a consistent soil classification within the sub-area followed by adjustment of the boundaries of the sub-areas as needed. Relevant guidelines on field classification of soils include:

- Schoeneberger, P.J., D.A. Wysocki, E.C. Benham, and Soil Survey Staff. 2012. Field book for describing and sampling soils, Version 3.0. Natural Resources Conservation Service, National Soil Survey Center, Lincoln, NE.
- Soil Survey Staff. 2014. Keys to Soil Taxonomy. 12th Edition. United States Department of Agriculture, Natural Resources Conservation Service
- Soil Survey Staff. 1999. Soil Taxonomy. A Basic System of Soil Classification for Making and Interpreting Soil Surveys. 2nd Edition. United States Department of Agriculture, Natural Resources Conservation Service. Agriculture Handbook No. 436.

A.2.3.2 Stratification by Topography and Vegetative Density

Where variation in slope is a significant characteristic of a landscape, stratification should also account for the topography (elevation, slope, aspect etc.). Common slope gradient categories are (1) very slightly inclined 1-2°, (2) slightly inclined 2-5°, and (3) medium inclined 5-10° (FAO, 2016; Jakši´c et al., 2021).In some cases, and especially in agricultural settings with minimal slope differences, including soil series as a stratification variable sufficiently accounts for variability in SOC caused by differences in terrain (Bergstrom, Monreal, Jacques et al., 2001).

For natural landscapes and areas with unevenly distributed plant growth, stratifying sample locations based on the vegetation density can be important to reducing variability. Vegetative density commonly estimated using Normalized Vegetation Difference Index (NDVI) and percent bare ground within a project site play a key role in controlling the spatial variability of soil organic carbon and should be considered in a sampling scheme (Oueslati et al., 2012).

A.2.3.3 Stratification by Land Management Methods

Stratification of the project area may include considerations of the intended or historical land management. Different land management approaches in the same project area will likely warrant separate sub-areas because the carbon accrual rates achieved by contrasting management may differ significantly. A few examples of contrasting management that should be included in a sampling plan are: a ranch that uses both traditional and adaptive multi-paddock (AMP) grazing; a site which includes actively cultivated or grazed areas and areas that are protected or restored to native vegetation; agricultural fields with contrasting tillage, cover crops, or rotations. If land management practices will not be consistent across the project area or is known to have varied historically, the difference in land management practices shall be considered a variable in the stratification process, where sub-areas defined upon consideration of the criteria in Sections A.2.3.1 and A.2.3.2 above are further divided based on management practices. The information on prior land management practices to be applied in various portions on the project area must be specified and maintained throughout the project period, and sub-areas established such that land management practices are consistently applied within each sub-area.

A.3 Combining Individual Properties into Group Projects

A.3.1 Overview of Group Project Criteria

In some cases, projects on separate properties can be combined as a "group project" to develop a more cost-effective sampling program by consolidating sampling efforts, allowing stratification of similar regions over a larger area, and combining the carbon credit application documentation Combining projects in this manner, however, requires that the properties share comparable soil and land characteristics and are subject to consistent land management practices such that SOC accrual rates will be comparable across the landscape. Group projects require advance review and approval by BCarbon based on demonstration that the proposed combined areas share consistent stratifying parameters and will be subject to the same sampling, testing, and monitoring methods, as well as consistent land management practices.

For this purpose, the same stratification process described in Section A.2 above for a single property shall be applied across the combined land area of the multiple properties that are proposed for the group project. Sub-areas may extend across property boundaries and be larger in area than the comparable sub-area defined for an individual property. With a grouped project, sampling from across the entire stratified landscape can be applied to each individual property without requiring intensive sampling on each individual property.

A.3.2 Factors for Assessing the Feasibility of a Group Project

When grouping multiple properties and/or landowners together, care must be taken to delineate and document individual sub-areas to demonstrate that landscape conditions and land management in each sub-area are sufficiently consistent that the results of the sampling and testing program can be deemed representative across multiple properties.

A.3.2.1 Need for Comparable Soil and Landscape Conditions Among Properties

All the criteria defined in Section A.2 above regarding the stratification of individual properties pertain equally to stratification of the multiple properties proposed for incorporation as a group project. The proposed area of the group project must be defined as described in Section A.2.1 and those portions of the group project area will not be actively used for carbon accrual (e.g., roadways, drainage ways etc.) shall be removed from the project area to be used for calculation of carbon accrual. Land areas in which stratifying criteria are sufficiently alike to qualify as a sub-area may be incorporated into a single sub-area without regard for property lines. The degree of natural variability in the landscape will determine the feasibility of a group project, however, as in landscapes where the stratifying parameters vary significantly over a relatively short distance sub-areas are likely to be limited in size and not extend over multiple properties.

A.3.2.2 Need for Comparable Land Management Practices

Stratification for group projects also includes consideration of the current and historical land management practices as specified in Section A.2.3.3 above for individual properties. The land management practices being applied on the individual properties must be consistent for each of the individual projects to be grouped together. In other words, the approach must incorporate the same general methodology or strategy, with site-specific modifications in land management practices as needed among individual properties.

A.3.2.3 Documentation of Site Stratification for Group Project

A report documenting the procedures and results of the stratification process for the properties to be incorporated into a group project will provide the basis for consideration of pre-approval of the group project by BCarbon. Documentation must explain the rationale for determination of sub-areas, provide supporting information, and include a scaled map of the sub-area locations and boundaries.

A.4 Readjustment of Sub-Areas Based on Subsequent Sampling Information

Following the initial stratification of the project area, the field and laboratory work completed as part of the beginning sampling program (see Standard Procedure B) may yield additional information regarding site conditions and below-ground carbon content in each sub-area. For example, the soil types may be observed to be different than assumed when the sub-areas were previously defined. Based on this new information obtained regarding stratifying parameters, the sub-area must be evaluated to assess the need to adjust the sub-area boundaries in order to meet the criteria specified in Section A.2 above.

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Bergstrom, D. W., Monreal, C. M., & St. Jacques, E. (2001). Spatial dependence of soil organic carbon mass and its relationship to soil series and topography. *Canadian Journal of Soil Science*, *81*(1), 53–62. https://doi.org/10.4141/S00-016

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Oueslati, I., Allamano, P., Bonifacio, E., & Claps, P. (2013). Vegetation and Topographic Control on Spatial Variability of Soil Organic Carbon. *Pedosphere*, *23*(1), 48–58. https://doi.org/10.1016/S1002-0160(12)60079-4

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Soil Survey Staff (b), Natural Resources Conservation Service, United States Department of Agriculture. Soil Data Viewer. Available online at https://www.nrcs.usda.gov/wps/portal/nrcs/detail/soils/home/?cid=nrcs142p2_053620. Accessed 7 February, 2021.

Soil Survey Staff (c). The Gridded National Soil Survey Geographic (gNATSGO) Database for Texas. United States Department of Agriculture, Natural Resources Conservation Service. Available online at https://nrcs.app.box.com/v/soils. December 1, 2020 (FY2020 official release).

STANDARD PROCEDURE B: MEASUREMENTS TO DETERMINE SOIL ORGANIC CARBON CONTENT

B.1 Overview and Objectives

This standard procedure specifies accepted methodologies for the sampling and analysis of soil cores from the project area for the purpose of quantifying the net change in soil organic carbon over the true-up period. These specifications for sampling and analysis of SOC at the beginning and end of each project period include determination of the appropriate number and location of sampling points. The results of these measurements shall be used to quantify the SOC accrued over the project period in accordance with the statistical procedures described in Standard Procedure D. The user may elect to use alternative procedures for sampling and analysis that provide equal or better reliability and accuracy than the methods described herein; however, such alternative methods require advance review and approval by BCarbon.

B.2 Definition of Soil Organic Carbon Under this Procedure

Soil organic carbon (SOC): The organic carbon stock, as determined by acceptable field and/or laboratory methods of soil organic carbon concentration and bulk density on properly collected samples, for the fraction of the soil sample that passes through a 2 mm sieve. Soil inorganic carbon (e.g., caliche, calcium carbonate, or dolomite) is not eligible for crediting.

B.3 Direct Measurement of Soil Organic Carbon at Start of the True-up Period

The goal of the initial sampling and analysis is to estimate the SOC stock in each designated sub-area (see Standard Procedure A) with sufficient statistical confidence to quantify of the net change in carbon content at the end of the true-up period. At each sampling location, samples shall be collected for analysis of SOC and bulk density. Measurement and documentation of other soil and land characteristics such as soil texture, vegetative density and diversity, and other relevant parameters are recommended to facilitate effective monitoring of the carbon accrual effort over time (see Standard Procedure C) and certification of interim credits. This standard sets forth separate procedures for sampling and analysis of soil organic carbon and bulk density.

Prior to sampling, we recommend that applicant take preliminary samples to get an on the ground understanding of SOC variation in the project site. After this step, a sampling plan shall be prepared and documented to describe:

- the rationale for and results of the stratification process.
- the number, location, and depths of samples to be collected within each sub-area.
- the sample collection and analytical methods to be applied.

Relevant specifications for determining the necessary number of samples in each sub-area, as well as procedures for sample collection, handling, and analysis are described below. If a sampling plan is not approved by BCarbon prior to implementation, BCarbon may accept sampling results for carbon crediting at their sole discretion if the plan employed for the project is consistent with this protocol.

B.3.1 Number and Location of Samples Required from Each Sub-Area

The number and location of samples in each sub-area shall be sufficient to characterize SOC stock with sufficient accuracy to be able to quantify the change in carbon over time. The more variable the carbon content from one location to another in each sub-area, the greater the number of samples required to distinguish the net change in carbon from the natural variability.

Sampling locations shall be selected throughout the sub-area to obtain a reasonable representation of the spatial variability of SOC content across the area. The environmental statistical literature lists various techniques that may be applied to select representative sample locations such as simple random sampling (Sanderman *et al.*, 2011; The Earth Partners, LLC, 2012).

Advanced techniques for determining soil sample locations such as conditioned Latin hypercube sampling (cLHS) and feature space coverage sampling (FSCS) may be used to select the location of soil samples if applicants:

1. Use the statistical approach laid out in Section B.3.1 of the protocol to estimate the number of samples required from each stratum to meet the 90% confidence interval requirement determining baseline soil carbon stocks.
2. Use the statistical approach laid out in Section D.2 of the protocol to determine the change in SOC stocks on the project site over the true-up period with appropriate statistical rigor.

B.3.1.1 Estimation of the Necessary Number of Samples Based on Specified Margin of Error on the Mean Carbon Concentration

Assuming that the soil organic carbon data are normally distributed in a sub-area, the number of samples required to characterize the mean concentration in each sub-area with sufficient statistical rigor can be derived using the following relationship, as specified in VCS Module VMD0021 of the Verra protocol:

Eqn B.1: Collect sufficient number of samples, n_i, in each sub-area i, such that:

$$\left(t \times \frac{s.d.}{\sqrt{ni}}\right) \leq 0.1 \times \left(\sum C\right) / n_i$$

Where:

$(\sum C)/n_i$ = The calculated average carbon content, in mass/unit area, in sub-area i, based on n_i sample measurements or approximated based on available information

n_i = number of samples collected in sub-area i or proposed to be collected in sub-area i

t = t-value in t-statistic for 90% level of confidence for the n_i samples collected in the sub-area (see NIST/SEMATEH, 2020)

$s.d._i$ = standard deviation of carbon content calculated for the dataset of n_i samples in sub-area i or approximated based on available information

This criterion requires that the margin of error (i.e., the difference between the upper and lower confidence limits) on the mean at a 90% level of confidence not exceed 20% of the value of the mean. For example, if the mean soil carbon value were 500 kg/m^2, then the 90% lower confidence limit on the mean (LCL) would need to be at least 450 kg/m^2 (within 10% less than the mean) and the upper confidence limit on the mean (UCL) would need to be no greater than 550 kg/m^2 (within 10% more than the mean). This calculation can be performed using the estimated mean concentration and standard deviation of the carbon concentration in the sub-area as determined from published information.

Preferably, an initial round of samples can be collected from the sub-area and analyzed, and the mean and standard deviation based upon these samples used to determine if additional samples will be needed to meet the specified margin of error criterion. Based on these results, Equation B.1 can be used to estimate the total number of samples likely to be required in each sub-area.

Testing of a portion of the sample population and recalculation of the required number of samples can be conducted on an iterative basis until the margin of error criterion is achieved.

B.3.1.2 Estimation of the Necessary Number of Samples Based on Nomographs for the Difference Between Means Criterion

As further discussed under Standard Procedure D of this protocol, the statistical procedure for estimation of the difference between means for the beginning and ending sampling programs is an alternative statistical methodology that can be applied for evaluation of the net change in below-ground carbon over time. Similar to the methodology described in Section B.3.1.1 above, the greater the number of samples collected, the lower the uncertainty in the estimation of the net change in carbon, and the greater the carbon credit obtained. However, the difference between means procedure applies a less stringent criterion for determination of the number of samples needed and may prove more practical for sites where the variability in SOC is significant.

For the "difference between means" method, Figure B.1 provides an example of a nomograph that can be used to assess the benefit of collecting and analyzing a given number of samples. All statistical methods discount the true increase in carbon by some fraction in order to account for uncertainty in the estimate. The nomograph on Exhibit B.1 shows the fraction of the anticipated increase that will be achieved based the degree of variability in the carbon content in site soils (expressed as the coefficient of variance), and the proposed number of samples that will be collected. This plot is for an anticipated carbon increase of 50% over the project period. In this example, we have determined the CV to be 0.5, based either on published data or a preliminary sampling program. Using the CV = 0.5 curve, we can then determine the fraction of the anticipated carbon increase that could be achieved for any given number of samples. For example, if we choose to collect and analyze 10 samples, we will achieve 0.6 of the anticipated increase or, in this sample, credit for 30% out of an anticipated 50% increase in carbon. If we chose to collect 40 samples, we would achieve 0.8 of the anticipated carbon increase or 40% credit out of the anticipated 50% increase. The user will need to assess whether the additional credit warrants the cost of the additional sampling.

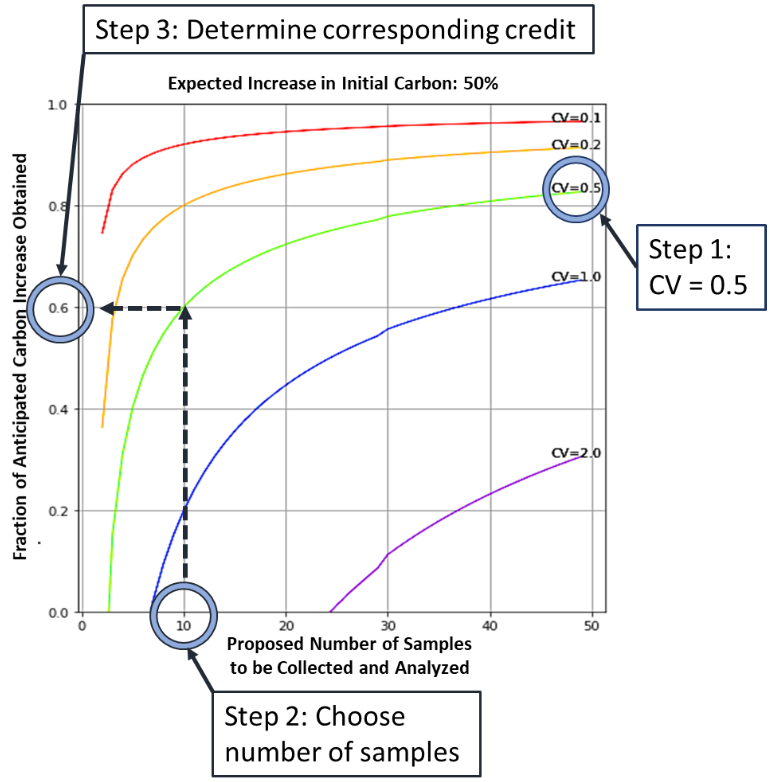
Figure B.2 provides nomographs for three levels of anticipated increases in carbon mass: 50%, 100%, and 200%. Based on the expected carbon gain over the project period, the user can select the appropriate chart to use. Note that these charts are simply a tool to assess the benefit of a smaller or larger number of samples. The true carbon credit will depend on the difference between the beginning and ending sampling as discussed in Standard Procedure D.

Figure B.1. Sample nomograph showing the carbon credits awarded as a function of variance and sample number assuming 50% increase in carbon content

Step 1: Determine Coefficient of Variance (CV): Based on published information or preliminary sampling and testing, calculate the CV of the sample set (standard deviation divided by the mean). In this example, our CV has been determined to be 0.5.

Step 2: Based on CV, select the applicable curve on chart (example curves provided for CV's = 0.1, 0.2, 0.5, 1, and 2). Applicable curve is the CV = 0.5 curve.

Step 3: Select a proposed number of samples to be collected and analyzed.



Step 4: For that number of samples, determine the corresponding credit to be obtained. In this example, for 10 samples, the CV curve indicates that we will qualify for 0.6 of the true carbon increase. If the true carbon increase is 50%, then we will get credit for a 0.6 x 50% = 30% increase.

Step 5: If greater credit is desired, increase the proposed number of samples. Or, reassess CV based on more sampling and testing and repeat the exercise. Based on more samples the CV may decrease, providing a more favorable fraction of credit for a given number of samples.

As noted in Section B.3.1.1 above, an iterative approach to sample analysis may be applied, wherein the user collects a larger number of samples than anticipated to be needed in each sub-area, analyzes only a portion of that sample population to estimate the standard deviation of the test results, and, on that basis, uses Figure B.2 to estimate the total number of samples likely to be required in each sub-area. Testing of a portion of the sample population and recalculation of the required number of samples can be conducted on an iterative basis until the estimated standard deviation and the corresponding number of samples required stabilize among iterations.

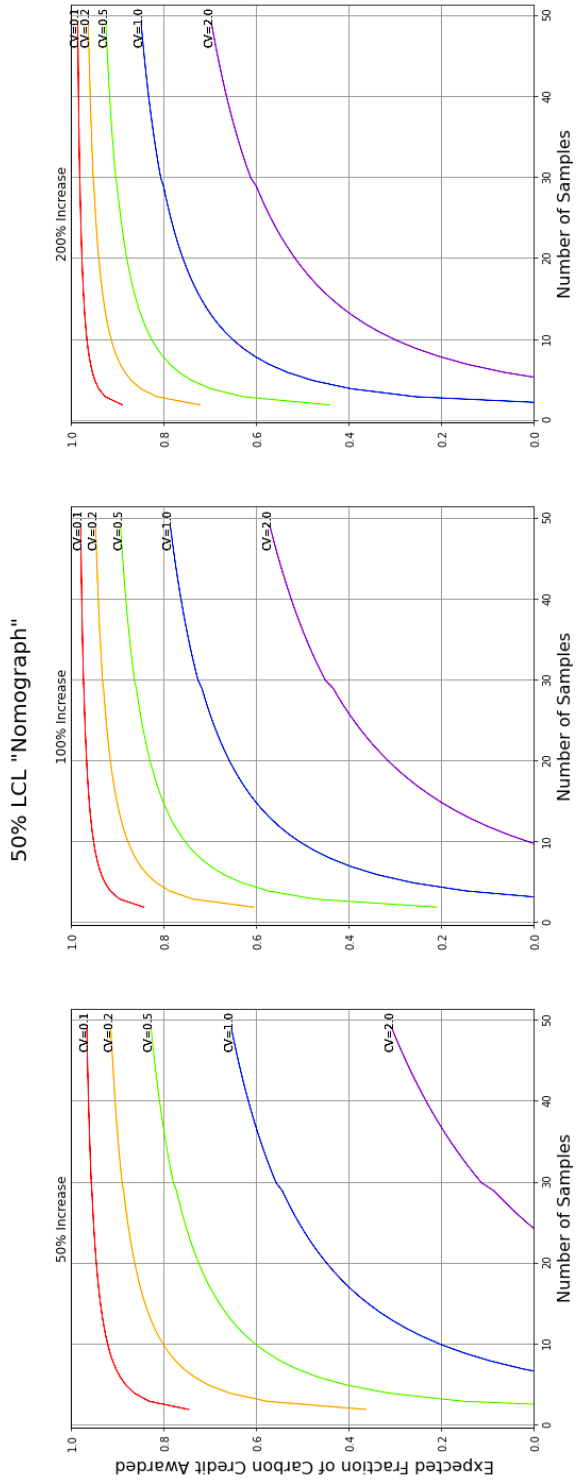


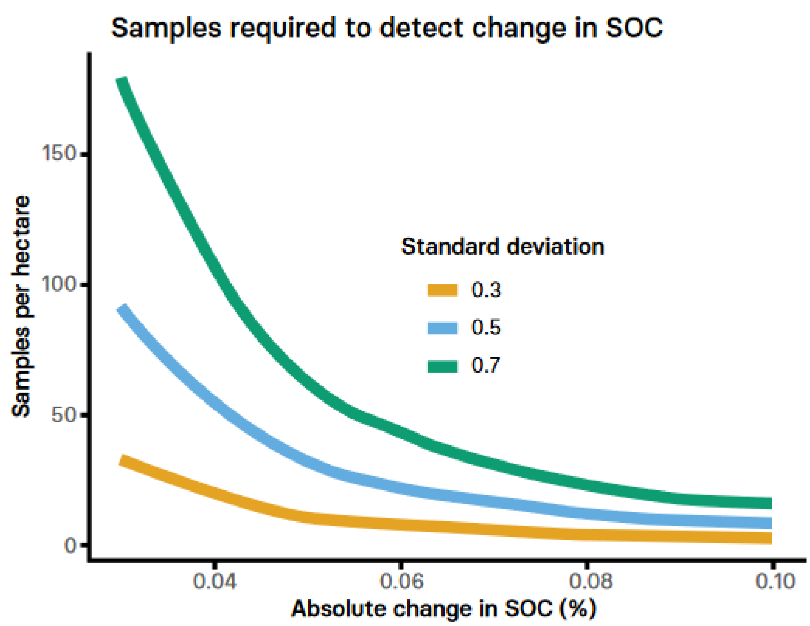
Figure B.2. Nomographs showing the expected fraction of carbon credits awarded (based on the 50% Lower Confidence Level (LCL)) relative to full crediting of the actual amount of carbon accrual as a function of the number of samples collected. Three scenarios are illustrated: an assumed 50% increase (left) in carbon accrual between the beginning and ending sampling efforts (left), and assumed 100% increase (i.e., doubling) in carbon accrual (middle), and a 200% increase in carbon accrual (right). Each line represents *a different level of variability in carbon measurements, expressed as the coefficient of variation (CV), which is equal to the population standard deviation divided by the population mean.*

To assess the sample size needed to detect a given change in SOC or estimate the probability of detecting a change with a given number of samples, we recommend conducting a power analysis. Power analyses can inform the sample size needed to detect a change in the mean SOC value given the best estimate of the variability (standard deviation) of SOC.

There are many online calculators that can aid in conducting a power analysis such as G*Power (see Faule et al., 2009) and an online calculator by the UCSF Biostatistics program (https://www.stat.ubc.ca/~rollin/stats/ssize/). A power analysis should include the best estimate of the current mean and standard deviation of SOC, a two-tailed test indicating the mean SOC value could go up or down, and paired sampling (variably described as comparing a mean to a known value) to what would be considered a meaningful change in SOC such as 0.04%.

The figure below demonstrates how a power analysis can inform sample size for a 50 ha field with three contrasting levels of variability in SOC for a given change in SOC over time. This figure was created by the Environmental Defense Fund report Oldfield et al. (2021)

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.

B.3.2 Defining the Sample Depth Interval

The depth of the soil in which significant carbon accrual may occur depends on the nature of the soil, the land management activity, and other factors. Based on a site-specific determination involving these scientific factors as well as project economics, the project proponents shall specify a defined sample interval. Commonly selected intervals include 30 to 100 cm. There is no specified depth interval for sampling under this procedure; however, it is required that the same depth interval must be used for both the beginning and ending sampling programs.

B.3.3 Procedures for Sampling and Analysis of Soil Organic Carbon

At each sampling location, representative soil samples shall be collected from the specified depth interval for analysis of soil organic carbon and soil bulk density. Various technical guidelines are acceptable under BCarbon regarding appropriate methods for sample collection and handling, including:

- USDA Kellogg Soil Survey Laboratory Methods Manual (KSSL Method Manual, Soil Survey Staff, 2014a)
- Australian National Soil Carbon Research Programme: Field and Laboratory Methodologies (Sanderman *et al.*, 2011)
- Standard soil methods for long-term ecological research (Robertson *et al.*, 1999)

Other publications of equivalent or higher rigor in soil sampling and testing methods are acceptable upon prior approval by the BCarbon.

Field Sampling Procedures for Soil Organic Carbon and Soil Density

Organic Carbon Samples: Samples for soil organic carbon analyses shall be collected for each specified depth interval. Initial and subsequent sampling should extend below the sampling depth sought for assessing C stocks by at least 5 cm in the event of changes in bulk density and SOC redistribution over time (VM0021 Soil Carbon Quantification Methodology, v1.0). A continuous soil profile of the specified depth interval shall be obtained with standard soil sampling equipment and subdivided into consistent depth intervals (e.g. 0-15, 15-30, & 30-35 cm; 0-10 cm, 10-20, and 20-30 cm, 0-5, 5-15, 15-30). Multiple soil cores may be taken from a sample location and composited by depth interval to further constrain soil heterogeneity, reduce project cost, and time (Spencer et al., 2011). Bulk density should be assessed separately for each depth interval sampled.

Projects with the expertise to do so may prefer to subdivide soil cores by soil horizon using guidelines specified in Standard Procedure A (Schoeneberger *et al.*, 2012; Soil Survey Staff, 1999; Soil Survey Staff, 2014b). For this method, cores should be rated into corresponding subsamples if multiple soil horizons presenting significantly different carbon contents are encountered. The measurement of SOC shall not involve compositing soil samples from two or more major soil horizons (e.g. A+B, O+A).

Bulk Density Samples: To convert the measured SOC *concentration* to a carbon *stock* for the purpose of crediting, the soil bulk density will also need to be measured at each sample location. Accurate measurement of the soil bulk density in the laboratory requires collection of an undisturbed soil core at each sampling location. The undisturbed core must be from the same or immediately adjacent location as the soil sample to be analyzed for carbon content. After collection, the soil sample must be preserved in a manner that retains its integrity and moisture content and maintains a cool temperature until delivery to the analyzing laboratory.

Laboratory Analysis of Bulk Density

The KSSL Methods Manual (Soil Survey Staff, 2014a) and other USDA field guides include further details on sample collection for analysis of soil bulk density. For soils that are sufficiently coherent to be removed as an undisturbed core, the clod method as described in the KSSL Method Manual or Donovan (2012) or the variable height method describe in KSSL Method Manual (*Field-State 3B6a*) may be used. For soils that are not amenable to collection of an intact, undisturbed sample, one of these following methods described in the KSSL Method Manual may be employed: (1) *compliant cavity* (*3B3a*), (2) *ring excavation* (*3B4a*), and (3) *frame excavation* (*3B5a*). Other acceptable laboratory methods include the KSSL Method Manual Saran-Coated Clods (*3B1a*), as well as ASTM Methods D2937 or D7263 or equivalent procedures.

Laboratory Analysis of Soil Organic Carbon

In the laboratory, the analysis of SOC shall be performed on air-dried soil samples that pass through a 2 mm sieve. Sample preparation involves the following steps (the relevant method name and code from the KSSL Method Manual are listed in *italics* as examples):

- Air-drying: *Air-Dry Preparation (1B1b2)*,
- Crushing and sieving: *<2-mm Fraction (1B1b2b)*, and
- Pre-processing for total carbon analysis: *<2-mm Fraction Processed to ≈180 μm (1B1b2d)*, and
- Pre-processing in order to determine the necessity of inorganic carbon analysis: *Presence of Carbonates (1B1b2d4)*

After proper sample preparation, the <2-mm fraction of the air-dried sample will be analyzed for total carbon content, as well as inorganic carbon, if the presence of carbonates is confirmed. Acceptable methods of analysis include:

- Total carbon content: KSSL Method Manual Dry Combustion (*4H2*), or Section 4.1 Measurement of carbon concentration in the Australian National Soil Carbon Research Programme (Sanderman *et al.*, 2011)
- Inorganic carbon content: KSSL Method Manual Calcium Carbonates (*4E1a1a1*), or Section 4.2 Calcareous samples in the Australian National Soil Carbon Research Programme (Sanderman *et al.*, 2011)
- Organic and inorganic carbon content: KSSL Method Manual Mid-Infrared Diffuse Reflectance Spectroscopy (MIR–DRS) (*7A7*) or Section 7 Mid-Infrared Spectroscopy in the Australian National Soil Carbon Research Programme (Sanderman *et al.*, 2011)

Measurement of soil carbon based on Loss on Ignition (LOI), or Walkley-Black analysis are not accepted under this protocol.

Calculation of Soil Organic Carbon Content

The soil organic carbon (SOC) stock (SCC) at each sample location is the depth-weighted summation of the soil organic carbon concentrations measured in each depth increment at each sampling location, calculated as follows:

Eqn. B.2 **SOC concentration per depth increment (mass of soil carbon per unit area) at sampling location**:

$$SOC_i = C_i \times h_i \times \rho_{b,i}$$

Where:

SOC_i = *estimated soil organic carbon stock of depth increment i at the sample location*

C_i = *soil organic carbon concentration (mass C/mass soil) in depth increment i, after subtracting any measured inorganic carbon (if applicable)*

h_i = *the length of depth increment i*

$\rho_{b,i}$ = *soil bulk density (mass <2-mm soil / volume soil) measured for depth increment i at the sample location.*

Eqn. B.3 **SOC content (mass of soil carbon per unit area) at sampling location:**

$$SCC = \Sigma SOC_i$$

Where:

SCC = *soil organic carbon content per unit area at the sample location*

SOC_i = *estimated soil organic carbon concentration for horizon i at the sample location (see eqn. B.2)*

B.3.4 Alternative Methods for Sampling and Analysis of Soil Organic Carbon

The sampling and analysis methods described above are conventional methods currently in use. Alternative methods to conduct these same measurements, employing special instruments and/or in-situ measurements, may be available at the present time or become available in the future to conduct these same measurements. Use of these alternative procedures requires prior review and approval by BCarbon based on scientific information demonstrating that the proposed alternative methods are applicable to the site-specific conditions of the project area and can provide a reliable estimate of the net change in belowground carbon mass over time.

B.3.5 Readjustment of Sub-Areas Based on Sampling Information

The field and laboratory work completed as part of the initial sampling program will yield additional information regarding site conditions and SOC in each sub-area. For example, the soil types may be observed to be different than assumed when the sub-areas were previously defined. Based on this new information, the sub-areas must be re-evaluated, and the sub-area boundaries adjusted as necessary to meet the criteria specified in Section A.2 of Standard Procedure A. The sampling plan should be revised to reflect these modified sub-areas and submitted for review and approval by BCarbon prior to use of the sampling plan for the sampling program at the end of the project. The rationale for the change in the boundaries of the sub-areas and the associated change in the distribution of soil samples must be documented in the project report (see Standard Procedure D).

B.4 Direct Measurement of Soil Organic Carbon at the End of the Project Period

B.4.1 General Procedures for Sampling and Analysis at the End of the Project Period

The direct measurement of SOC at the end of the true-up period shall apply the same sampling and analytical methodologies applied in the initial measurement, to minimize the variability introduced by changes in methodology. All other provisions of Section B.3 related to sampling and analytical procedures apply equally to the end of the project sampling program, including the approach used to determine the necessary number and location of samples. The project area must be adjusted to delete portions of the land area that are no longer amenable to the land management program used to enhance SOC. Examples of such changes might include the inundation of a portion of the project area by surface water, development, or depositional events originating from outside the project area.

Sampling at the end of the project period shall take place at approximately the same time of year as at the start of the project period. For example, if sampling takes place in early May during the initial sampling, then the sampling should also take place in early May at the end of the project period. Various methods may be employed, including time of year (e.g., month), degree-days since the start of the growing season, or after a readily definable metric (e.g., planting or harvesting). The intent is to calculate the inter-annual change while minimizing the effects of seasonal changes.

The time when the end of project sampling will be conducted is a site-specific decision at the discretion of the project owner or manager.

B.4.2 Possible Corrections to Measured Belowground Carbon Content at the End of the Project Period

Significant changes over the project period to the soil bulk density or soil erosion or deposition patterns require adjustment of the end of project SOC measurements, as discussed below.

Corrections Based on Changes in Soil Bulk Density

In some instances, changes in land management activities can result in significant changes in soil bulk density (e.g., over time, the soil becomes either less dense and more porous or denser and less porous). This change in bulk density over time affects the calculation and comparison of beginning and ending carbon content in the soils. If the average bulk density measured in a sub-area between the beginning and ending sampling programs differs by more than 5%, additional steps in the ending sampling and analysis program will be warranted to ensure comparison of an equivalent mass of soil in each sampling program. The following publications provide guidelines for these additional steps:

- Measuring Soil Carbon Change. A flexible, practical, local method, Section 4.11, Correcting for changes in bulk density in (Donovan, P., 2012), or
- VCS VMD0021 Estimation Of Stocks In The Soil Carbon Pool, Section 6.2a Changes in Soil Density (The Earth Partners LLC, 2012)

Corrections Based on Effects of Erosion/Deposition of Soil

Over the course of the project period, significant changes to the landscape in the project area may occur due to erosion or deposition of soil or sediments. In general, erosion can reduce SOC from an area by moving the surficial soil layers that contain the highest SOC elsewhere. To avoid such effects, portions of the project that experience events contributing to soil deposition or erosion (e.g., inundation during a flood) must be excluded from the project area for the purpose of calculating the net gain in SOC. Alternatively, the project owner or manager can provide information for review and approval by BCarbon demonstrating that, based on sampling, the net gain in carbon content can be reliably adjusted for the effects of such erosion or deposition.

B.5 Documentation of the Sampling and Analytical Program

For both the beginning and ending sampling programs, a report shall be compiled documenting the number and locations of samples, the sample collection, handling, and laboratory test methods, and the results of the field and laboratory analyses. The report must identify each sub-area and provide analytical and statistical results for each. Standard Procedure E provides detailed specifications for project record-keeping and reporting.

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STANDARD PROCEDURE C: MONITORING, MODELING, AND FORECASTING OF SOIL ORGANIC CARBON ACCRUAL

Interim Credit Policy

To mitigate risk and streamline application throughput, BCarbon is issuing interim credits under the following conditions as of the date of this Protocol:

1. Interim credits must be requested in geographic regions that have relevant peer-reviewed literature which report soil carbon sequestration rates and have similar climatic and land management practices.
2. Historical test results, if available and done in a similar fashion to our protocol, may supplement or replace peer reviewed literature at our discretion. Note that historical testing results prior to 2019 are not eligible for use as baseline measurements nor will credits be issued for years prior to 2019. Exceptions may be granted if warranted.
3. Baseline soil carbon measurements must have been completed in accordance with Standard Procedure B of the Soil Metrics Protocol prior to the interim credits being issued. At BCarbon's discretion no final crediting decision will be made until baseline laboratory results are completed and received.
4. Generally, issuance of interim credits will be limited to one ton of carbon dioxide equivalent per acre per year over the given project area. In exceptional cases, BCarbon may issue interim credits for values higher than one ton of carbon dioxide equivalent per acre per year at its discretion. Any issuance of interim credits for a given year in a specific project does not imply the same number of interim credits will be issued again at the same rate or at any point in the project's future. All interim crediting decisions at project onset and throughout the project's lifecycle are at the discretion of BCarbon. Stand-alone proprietary models will not be considered in our standard formal review during 2022.
5. Interim credits may only be issued a maximum of 5 times prior the true-up period.

C.1 Overview and Objectives

Sampling and analysis of SOC at the beginning and end of the true-up period, is required to quantify SOC stock change. Soil carbon dynamics modeling and/or indirect measurements of organic carbon may optionally be employed to provide a multiple lines-of-evidence approach to estimation of the rate of carbon accrual.

Forecasting methods are not a replacement for direct measurement of SOC at the beginning and end of the project period. In all cases, properly obtained, direct measurements of SOC content (see Standard Procedure B) are to be considered more reliable than models or other estimation methods, when available for the same project area and time. However, in the absence of additional direct measurements between the starting and ending sampling episodes, monitoring of indicator parameters and/or modeling of SOC accrual rates can increase confidence that belowground carbon accrual is taking place and support certification of interim carbon credits.

This standard procedure provides specifications for two optional methods of forecasting or estimating carbon accrual rates in the project area: i) modeling of the rate of SOC accrual rates using analytical or numerical models of soil carbon dynamics, and ii) estimation of carbon accrual over time based on empirical relationships or checklists that rely on performance indicators, such as the vegetative density, soil moisture content, and other measures of soil health. If either of these options is to be used to justify issuance of interim carbon credits, care must be applied to avoid over-estimation of carbon accrual during the project period. For this purpose, the uncertainty in the estimation method must be quantified and documented, and the method applied to provide a conservative (low) estimate of the accrued carbon concentration at the end of the project period.

C.2 Forecasting of Soil Organic Carbon Accrual Using Modeling

C.2.1 General Specifications on Model Use

Models of SOC dynamics may be employed under this standard to estimate the accumulation of SOC in the time period between the direct sampling events at the beginning and end of the true-up period. In addition, the use of models, when combined with in-situ measures of SOC accrual and other spatial datasets, may provide a more accurate estimate of SOC accrual than any one data source alone. An in-depth description of appropriate models and modeling steps is outside the scope of this standard procedure. However, this standard defines acceptable procedures for use of models by persons with adequate training, experience, and expertise to properly select and run these models and interpret the results.

Acceptable methods for forecasting SOC accrual include publicly available, scientifically accepted models that properly simulate the project soil, landscape, and climate conditions, as well as the land management practices being applied. Input parameters used for forecasting must match actual project conditions and be adjusted as necessary to achieve a conservative (low) estimate of the potential rate of carbon accrual over time. The applicability of the model to the project conditions and the appropriateness of the model inputs must be documented based on site-specific measurements and observations, as well as professional judgment.

C.2.2 Specifications on Model Selection, Inputs, and Management of Uncertainty

This standard permits the use of any widely accepted SOC dynamics model, as determined through peer review, public availability, and literature references (e.g., cited in a reputable peer-reviewed journal). Examples of acceptable models include DayCent/CometFarm and RothC (Grosso *et al.*, 2012; Parton, 1996; Campbell and Paustian, 2015). These models include user documentation that can be consulted to properly utilize the model for forecasting of soil organic carbon accrual under this standard. In addition, any caveats or restrictions on the model shall be reviewed with regard to the applicability and reliability of the model for the project in question.

The necessary input parameters and datasets for the model must be shown to be relevant to the specific model area or sourced from site-specific data using scientifically accepted methods (e.g., methods published by the USDA or Soil Science Society of America). Default model parameters shall also be reviewed for their applicability to the area being modeled. Confidence in model results can be improved by correlation with the performance indicators described in Section C.3 below. Advanced statistical and data fusion approaches (e.g., Bayesian approaches) may be employed to utilize both the model results and the field data to provide a more accurate estimation of soil carbon accrual within the project area.

Given the inherent uncertainty in model input parameters, as well as natural variability across the landscape, a sensitivity study shall be performed, where the input parameters are varied within reasonable and scientifically defensible bounds. The output of this sensitivity study can then be evaluated to establish reasonable bounds of uncertainty. The sensitivity study may further highlight those variables for which additional site-specific information may be collected to reduce uncertainty and thus increase reliance on the model output. After quantification of model uncertainty, the model forecast shall be adjusted to provide a conservative (low) estimate of the soil carbon concentration at the end of the project period. Specifications for model documentation and reporting are provided in Section C.4 below.

C.3 Estimation of Soil Organic Carbon Accrual Based on Performance Indicators

C.3.1 General Specifications on Use of Performance Indicators

Between the time of the direct sampling programs conducted at the beginning and end of the true-up period, effective accrual of soil organic carbon can be confirmed by monitoring of a variety of environmental parameters. Indicators of successful carbon accrual include increasing vegetative cover, abundance, and diversity; improved soil moisture content; changes in soil texture; and other measures of soil health. In combination with modeling forecasts, tracking of these indicator parameters can increase confidence in the estimated rate of SOC accrual over the true-up period. In addition, as either an alternative or a supplement to modeling, progress in these indicators can be used to estimate the rate of carbon accrual based upon simple empirical relationships or a scorecard approach. To this end, within the context of a particular climate, ecoregion, soil type, and land management activity, for example, these performance indicators may be related to a carbon accrual rate derived from the existing scientific literature, ongoing research studies, test plots, and other relevant sources of information.

Procedures for monitoring and interpretation of performance indicators are outlined below. As noted above, monitoring of this nature is not required under this protocol but can provide useful information for managing the carbon accrual project. However, if such monitoring is to be used to estimate carbon accrual rates for the purpose of applying for interim carbon credits before the end of the project period, the proposed program for monitoring and interpretation of these data will require advance review and approval by BCarbon.

C.3.2 Monitoring of Performance Indicators of Soil Organic Carbon Accrual

Periodic observation of certain physical and biological parameters can provide a reasonable assurance that soil health is being maintained or improved and that effective progress is being made toward the measurably increasing the SOC content in the project area. In addition, as discussed in Section C.3.3 below, these data can provide the basis for estimation of carbon accrual rates, in some cases.

The following indicators may be employed to confirm the occurrence and general rate of carbon accrual:

- Decrease in soil erosion (via wind or water);
- Decrease in bare soil;
- Increase in abundance/diversity of vegetation;
- Increase in deeper rooted annual or perennial plants;
- Increase in plant litter cover.
- Darker soil color, such as tracked by USDA Munsell soil color chart
- Reduced root resistance due to platy structures or layers in soil
- Increase in soil porosity and soil aggregate stability, contributing to reduction in soil bulk density
- Increase in water infiltration and soil moisture holding capacity, and/or decrease in surface runoff;
- Increase in abundance, diversity, density, and mass of earthworms and other soil fauna

Remote sensing data can also provide information in land changes that are indicative of improved soil health and carbon retention. Scientific work is underway to establish correlations between soil organic carbon and remote sensing parameters; however, it is anticipated that spatial patterns of the following parameters may provide qualitative and/or quantitative information on changes in SOC over time:

- Soil moisture products from the SMAP (Soil Moisture Active Passive) satellite;
- Relative degree of drought (e.g., Palmer Drought Severity Index (PDSI); https://www.drought.gov/drought/data-maps-tools/current-conditions)

- Surface temperatures and derivative products (e.g., evapotranspiration rate, etc.);
- Precipitation; and
- Vegetation indices (e.g., Normalized Difference Vegetation Index (NDVI).

The presence of one or more of positive indicators serve as evidence that soil carbon accrual has taken place, thus increasing the confidence in the predicted rate and mass of belowground carbon accrual, as predicted by soil dynamics models, empirical estimates, or other tools.

C.3.3 Estimation of Soil Organic Carbon Accrual Based on Performance Indicators

Periodic monitoring of the various performance indicators described above can be used to confirm a positive trend in SOC accrual over time in the project area. For that purpose, visual and physical observations can be recorded at selected time intervals (e.g., at the start of the project and annually thereafter) to establish the course of key indicators within each sub-area. These observations may include time-stamped field photographs, quantitative surveys of vegetative cover, diversity, and density; field inspection of soil texture, color, aggregation, and other characteristics using standard classification indices; time-stamped remote sensing images or other geospatial products (e.g., PDSI over time at regular intervals); or measures of other relevant indicator parameters, such as those described in Section C.3.2.

On this basis, a scorecard system or empirical relationships can be employed to approximate the rate of accrual of soil organic carbon. Such methods must draw upon existing scientific literature, ongoing research studies, test plots, and/or other relevant sources of information to estimate carbon accrual in the context of the relevant climate, ecoregion, soil type, and land management activity.

C.4 Documentation of Estimated Soil Organic Carbon Accrual for Purpose of Interim Carbon Credits

If modeling, as discussed in Section C.2 above, is employed to support interim carbon credits during the project period, a report must be submitted to BCarbon at the time of the request. This report must document the model selection, input parameters, modeling process, and modeling results. The rationale for selecting the chosen model shall be explained, and any caveats or limitations shall be clearly documented. Each input parameter shall be listed and documented with supporting information, including any site-specific data or the rationale for selecting a default parameter. A summary of any sensitivity analyses shall be presented and interpreted within the context of the soil carbon accrual process.

Similarly, if estimates of SOC accrual based on performance indicators, as discussed in Section C.3 above, are to be used to support interim carbon credits during the true-up period, the basis for these estimates must be documented in a report submitted to BCarbon at the time of the request. The report must explain the relevance of the performance indicators to the specific project, the data collected in the project area, and the interpretation of these data, supported by scientific references.

The reports for either modeling or estimation must demonstrate that the methodology provides a conservative (low) estimate of the soil carbon content that will be achieved at the end of the true-up period, such that interim carbon credits can be awarded without the likelihood of exceeding the total carbon credits warranted by the project. At the end of the project period, the model predictions and/or estimations shall be compared with the actual measurements of soil organic carbon. In the event of any discrepancies, the actual carbon measurements will be considered more reliable than the results of modeling or estimation.

References

Campbell, E.E. & Paustian, K. 2015. Current developments in soil organic matter modeling and the expansion of model applications: a review. Environmental Research Letters, 10: 123004.

Del Grosso, S.J., Parton, W., Adler, P.R., Davis, S., Keogh, C., Marx, E. 2012. DayCent model simulations for estimating soil carbon dynamics and greenhouse gas fluxes from agricultural production systems. Book Chapter. New York, NY: Elsevier Inc. p. 241-250.

Parton, W.J. 1996. The CENTURY model. In: Powlson, D.S., Smith, P. & Smith, J.U. (Eds.) Evaluation of soil organic matter models. NATO ASI Series (Series I: Global Environmental Change), Vol. 38. Springer, Berlin, Heidelberg. pp. 283-291.

STANDARD PROCEDURE D: STATISTICAL METHODS FOR QUANTIFICATION OF SOIL ORGANIC CARBON ACCRUAL BASED ON DIRECT MEASUREMENTS

D.1 Overview and Objectives

This standard procedure specifies the statistical methods that will be applied to quantify the net change in SOC content in the project area over time. Statistical methods provide a mathematical means to account for the natural variability in soil carbon content and estimate the net change from the beginning to the end of the true-up period with a specified degree of confidence. The methods discussed in this standard procedure are considered acceptable for this purpose; however, the user may demonstrate that other statistical methods are equally or more reliable based on scientific and statistical literature, subject to prior review and approval by BCarbon.

This standard procedure provides two methods for quantifying the net change in SOC over the true-up period: i) estimation of the difference in the beginning and ending mean carbon content of each sub-area by subtracting the beginning mean carbon content, estimated within a specified margin of error, from the ending mean carbon content, estimated within that same margin of error, or ii) estimation of the lower confidence limit of the “difference between means” relationship for the beginning and ending sample populations. Method ii is provided as an Appendix to the protocol.

Alternative statistical procedures, such as non-parametric methods, may be used. However, such alternative methods will require prior review and approval by BCarbon demonstrating that the proposed alternative methods are applicable to the site-specific conditions of the project and can provide a reliable estimate of the net change in SOC content over time.

D.2 Use of Conventional Parametric Statistical Approach to Estimate Net Change in Soil Organic Carbon Content

Following the statistical calculation approach laid out by Verra (VCS Module VMD0021), for any data set of samples collected and analyzed for carbon concentrations in a given sub-area, the mean carbon concentration with 90% margin of error is:

Eqn D.1: $$C = (\sum C_j)/n \pm [t \times \frac{s.d.}{\sqrt{n}}]$$

Where: *C = mean carbon concentration within a particular stratum*

*C_j = carbon content (**SCC** in Eqn **B.3** in units of mass/unit area, in sample j in a given sub-area*

n = number of samples collected in the sub-area

t = t-value in t-statistic for 90% confidence interval for the n samples collected in the sub-area (see NIST/SEMATEH, 2020)

s.d. = standard deviation of carbon content in data set

And: *C_i = C calculated per Eqn. D.1 based on the test results in the sub-area at the beginning of the project period*

C_f = C calculated per Eqn. D.1 based on the test results in the sub-area at the end of the project period

If the depth interval (b) of the carbon accrual zoned has been subdivided into two or more soil horizons (e.g., a shallow interval, 0 – 30 cm, and deep interval, > 30 cm), the values of C_i and C_f are derived as depth-weighted means calculated as described in Section B.3.2 of this protocol.

The margin of error, which corresponds to the second term in Equation D.1 (after the +/-), defines the upper and lower bound of the estimated mean SOC concentration within a 90% level of confidence. The smaller the margin of error is relative to the mean value (the first term in Equation D.1), the more precise and reliable the estimated mean and the calculated net increase in soil organic carbon that is based on the estimated mean. For estimation of the beginning and ending carbon concentration within a given sub-area, the target shall be to achieve a margin of error at a 90% level of confidence that is no greater than 10% of the value of the mean (e.g., if the mean carbon concentration is 100 mg/kg, the margin of error shall be no greater than 10 mg/kg).

If the margin of error for either C_i or C_f exceeds this target, the estimated carbon mass at the beginning or end of the project period will be adjusted as indicated in Equations D.2 and D.3 below:

Eqn D.2: $C_i = beginning\ sample\ mean \times \left(1 + [(\frac{margin\ of\ error}{sample\ mean}) \times 100\% - 10\%]\right)$

Eqn D.3: $C_f = ending\ sample\ mean \times \left(1 - [(\frac{margin\ of\ error}{sample\ mean}) \times 100\% - 10\%]\right)$

The criterion for the margin of error (i.e., that the 90% confidence limits on the mean be within +/- 10% of the estimated mean) can be used to estimate the number of samples that will be necessary to measure the mean soil organic carbon content with adequate precision at the beginning of the project (see Standard Procedure B).

Eqn D.4: $\Delta C = C_f - C_i$

Where: C_f *and* C_i *are obtained from Equations D.2 and D.3, respectively*

Values of the mean SOC content at the beginning (C_i) and end (C_f) of the specified true-up period meeting the margin of error criterion (or adjusted as needed per Equations D.2 and D.3) are used in Equations D.6 through D.8 below to calculate the net increase in soil organic carbon for the project area.

In situations with moderate to high variability of sample measurements, the discount on the beginning and/or ending sample mean specified in Equations D.2 and D.3 may be substantial and significantly reduce the mass of carbon accrual estimated using this method. As such, an alternative statistical approach based on the difference between means provides another statistical approach with sufficient conservatism, as described in Appendix 1.

D.3 Use of "Difference Between Means" Statistical Approach to Estimate Net Change in Below-Ground Carbon Concentration

The "difference between means" statistic provides an alternative method for estimation of the net change in the mean carbon concentration in each sub-area over the project period. With this approach, the difference in the mean carbon concentration is not determined by subtracting the estimated mean at the beginning of the project period from the estimated mean at the end of the project period. Rather, the "difference between means" is itself the parameter of interest, subject to a specified level of statistical confidence, and represents carbon accrual between the beginning and ending of the project period.

The net change in the mean carbon concentration in each sub-area is conservatively estimated as:

Eqn D.5: $\Delta C = (C_F - C_0) - [z \times S_p\sqrt{\frac{1}{n_F} + \frac{1}{n_0}}]$

Where: C_F *= Average carbon concentration in sub-area at end of project period (in mass per unit area)*

C_0 = Average carbon concentration in sub-area at beginning of project period (in mass per unit area)

n_F = number of samples collected in the sub-area at end of project period

n_0 = number of samples collected in the sub-area at beginning of project period

z = z-value in z-statistic for 50% confidence interval for the n samples collected in the sub-area (see NIST/SEMATEH, 2020); Note: if the number of samples are less than 30, use the t-statistic in lieu of the z-statistic

S_p is the pooled estimate of the common standard deviation, where:

$$S_p = \sqrt{\frac{(n_0-1)s_0^2+(n_F-1)s_F^2}{n_F+n_0-2}}$$

s_F = standard deviation of carbon content in data set at end of project period

s_0 = standard deviation of carbon content in data set at beginning of project period

If the depth interval (b) of the carbon accrual zoned has been subdivided into two or more soil horizons (e.g., a shallow interval, 0 – 30 cm, and deep interval, > 30 cm), the values of C_0 and C_F are derived as depth-weighted means calculated as described in Section B.3.2 of this protocol. Similarly, if heterogeneity in vegetation density is significant, the C values, namely RCC_j, are derived as vegetation-density-weighted means as described in Section B.3.4.

Eqn. D.5 provides the 50% Lower Confidence Level (LCL) on the difference between means, which, assuming normality, signifies that the true difference in means (i.e., the net change in mean carbon concentration in the sub-area over the project period) is equal to or higher than this value 75% of the time. The calculated carbon accrual is a consistent underestimate of the true carbon accrual and provides a conservative basis for the crediting approach.

Eqn. D.6, D.7, and D.8 are subsequently applied to calculate the net below-ground carbon *mass* accrued for the entire project area.

D.4 Calculation of Mass of Soil Organic Carbon Accrued in Each Sub-Area

Within each sub-area of the project area, the mass of below-ground carbon accrued over the course of the project is defined as the net difference in carbon stock at the beginning and end of the project:

Eqn D.6: Net Carbon Mass Accrued in Sub-Area = (ΔC) x (A_i)

*Where: **ΔC** = The difference in the mean carbon concentrations (in mass per unit area) between the beginning and ending sampling programs, as derived using either Eqn. D.4 or Eqn. D.5, above for the sub-area*

A_i = Area of sub-area, corrected for portions that are not available or not amenable to carbon accrual

The net carbon mass for the full project area, combining all sub-areas, is:

Eqn D.7: Net Carbon Mass Accrued in Project Area = Σ (Net Carbon Mass Accrued in Each Sub-Area)

This analysis is conducted for soil organic carbon, and the net increase in the below-ground carbon mass is calculated as:

Eqn D.8: ***Net Below-Ground Carbon Mass Accrued = Net Mass of Soil Organic Carbon Accrued***

D.5 Documentation of Procedures and Results for Estimation of Soil Organic Carbon Accrual

The project report shall document the procedures and results for the estimation of the mass of soil organic carbon accrued in the project area over the course of the project. Records shall include the complete set of concentration measurements used to calculate the mean carbon mass in each sub-area (in units of mass per unit area) at the beginning and end of the project period, the calculation methods and results, and any adjustments made to the calculated means to account for an excess margin of error (Equations D.2 and D.3). If statistical methods other than those described here are used for estimation of mean SOC content and/or the net increase in SOC content, the applicability and reliability of these alternate methods shall be demonstrated, and the associated calculation and results provided in the report.

REFERENCES

Berhongaray, G., Cotrufo, F.M., Janssens, I.A. and Ceulemans, R. 2019. belowground carbon inputs contribute more than above-ground inputs to soil carbon accrual in a bioenergy poplar plantation. Plant and Soil, 434(1-2), pp.363-378.

NIST/SEMATECH e-Handbook of Statistical Methods, https://www.itl.nist.gov/div898/handbook/eda/section3/eda3672.htm, accessed on 13 December, 2020.

STANDARD PROCEDURE E: DOCUMENTATION OF THE PROCEDURES AND RESULTS OF BELOWGROUND CARBON ACCRUAL PROJECT

E.1 Overview and Objectives

To be eligible for certification by BCarbon, a final project report shall be produced. The goal of documentation and reporting is to create a certifiable and verifiable record of each key data input, field measurement, and project decision point, as well as all calculations supporting the modelled, estimated, and/or measured mass of carbon accrual. This Standard Procedure provides guidance on how to organize this report and the minimum required information that shall be considered for project eligibility by BCarbon.

E.2 Documentation of Soil Organic Carbon Accrual Project

The final report will contain the following sections (or equivalent appendices) and associated recordkeeping. Suggested lengths are provided for each report section, with the understanding that lengths will vary based upon the nature of the project.

1. **Executive Summary (2 to 3 pages):** Summary of the report, addressing the project area, the land management methods applied, the results of the beginning and ending sampling events, and the calculated net gain in soil organic carbon content over the true-up period. If any interim credits have been issued during the project duration, these should also be documented in the Executive Summary.
2. **Project Methodologies (1 to 2 pages):** Description of the land management practices applied to increase SOC accrual in the project area, as well as supporting information on the efficacy of these practices. Identify the methodologies applied for stratification, sampling, laboratory analysis, and statistical evaluation by reference to accepted scientific guidelines, standards, and laboratory methods employed throughout the project duration.
3. **Definition of Project Area (1 to 2 pages):** Description and map of the project area and boundary, corrected for portions of that area that are not included in or not amenable to the carbon accrual effort.
4. **Stratification of Project Area (2 to 3 pages):** Detailed description of the stratification process and results, including each of the datasets (e.g., GIS files, remote sensing images, soil survey units, etc.) used during the process and a summary narrative describing the stratification process, key information uses, and rationale between the final stratification employed in subsequent sampling.
5. **Sampling plan Description (1- 2 pages):** A summary narrative describing the process used to select sampling locations, as well as any statistical procedures and calculations used during this process to determine the necessary number of samples, etc. The formal sampling plan shall be provided as an appendix to the report.
6. **Field sampling records (1 to 2 pages)**: Description of sampling programs for soil organic carbon, including number and location of samples, with accompanying maps. A detailed field sampling record, with dates and times of sampling, sample descriptions, and field photos for each sampling event shall be provided as an appendix to the report.
7. **Laboratory analytical results (1 to 2 pages):** Summary description specifying the analytical methods used, laboratory QA/QC, detection and quantitation limits, analysis results, and lab confirmation of the reliability of results. Analytical results shall be included in tabular format and plotted on a project map(s). Laboratory reports provided by the analytical laboratory must be included as an appendix to the main report.
8. **Modeling, estimation and monitoring records (2 to 3 pages):** If employed, a description of the modeling, estimation, and monitoring records employed to support interim estimation of net gain in carbon over the project period. The tracking of performance indicators over time

shall be documented with field forms and photographs. If modeling is utilized, the modeling files shall be included as a separate appendix electronically.

9. **Project Results (2 to 4 pages):** Documentation of the estimated mass of carbon accrual over the project period. A summary narrative and supporting calculations that describe the procedures and results must be included. All statistical calculations used to estimate the soil organic carbon accrual, including references for any statistical procedures that are utilized, shall be described, with associated calculation incorporated as an appendix to the report. Address any necessary adjustments to the carbon mass due to any uncertainties in the measurements or calculations or the instability of the carbon mass over the ensuing 10-year period. Provide documentation explaining the rationale and calculations behind these adjustments.
10. **References:** Citations for any references in the project report.

11. **Appendices of Supporting Information (as needed)**

    Appendix A: Project Methodologies

    Appendix B: Project Area Description

    Appendix C: Sampling Plan

    Appendix D: Field Records of Sample Collection

    Appendix E: Monitoring of Performance Indicators

    Appendix F: Laboratory Analytical Records

    Appendix G: Modeling and/or Estimation of Carbon Accrual Rates

    Appendix H: Statistical Evaluation of Net Gain in Belowground Carbon

    Appendix I: Other Supporting Information