Plains CO$_2$ Reduction (PCOR) Partnership

A SAMPLING PROTOCOL FOR MONITORING, MEASUREMENT, AND VERIFICATION OF TERRESTRIAL CARBON SEQUESTRATION IN SOILS

Value-Added Report

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April 2010

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TABLE OF CONTENTS

PCO2R Partnership
Plains CO_2 Reduction (PCOR) Partnership
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INTRODUCTION

Terrestrial carbon sequestration is a promising means for reducing atmospheric carbon dioxide (CO_2). To offset carbon emissions, improved land uses involving conservation practices are needed. The effectiveness of land use practices can be verified and monitored by documenting changes in soil organic carbon levels.

Universal standards proposed by the Intergovernmental Panel on Climate Change (IPCC) (2006a) for methods and procedures for measuring and verifying soil organic carbon (SOC) stored in a terrestrial system are utilized. The net increases in organic carbon added to a project area over a specific time period, verified and monitored using these methods and procedures determines the success of the project.

Rationale

The purpose of this protocol is to establish standards for gathering data collected from an inventory of carbon mass stored in soils. This guide asserts the primary objective of soil carbon monitoring, measurement, and verification is to produce reliable data, quantification, and documentation so that terrestrial sequestration projects can generate carbon offsets for trade on the open market.

This protocol provides a method for measuring changes in carbon mass stored in soils due to changes in soil management. Soils are highly variable. In order to provide the most accurate measurement of changes in stored soil carbon, a reliable, reproducible procedure must be used. The key to obtaining reproducible results is consistency in soil sampling, soil processing, and the use of an accepted analytical methodology for soil carbon measurements. Monitoring carbon change involves collection of representative soil samples from land areas of interest, determination of soil bulk density**,** and sample processing and analysis. Information obtained through the use of this protocol can be utilized in applications involving Tier 1 and Tier 2 evaluations of changes of carbon stocks in soils as proposed by IPCC for mineral soils under cropland and grassland management (Intergovernmental Panel on Climate Change, 2006b–d).

Although soil-sampling procedures have been used for over 50 years to measure changes in soil organic matter (carbon), soil bulk density measurements have rarely been used to adjust the soil carbon content for changes in soil condition due to soil management practices or tillage. Both management and tillage have dramatic impacts on soil condition. Determination of soil bulk density is a key component in this process in order to account for changes in management practices which directly impact the soil's ability to store carbon (organic matter). This protocol provides the procedures to accomplish these tasks.

Factors in Inventory Design

There are two approaches to inventory design that can be considered as means to estimate or inventory soil carbon:

- The first approach for determining soil carbon levels is an indirect method. This method uses global positioning systems (GPS), aerial photography, remote sensing, topographic maps, carbon sequestration models, geological surveys, and random soil sampling to estimate soil carbon.

- The second approach for verifying soil carbon levels is the use of a direct method. A direct method is the preferred inventory design procedure to utilize because it produces the most reliable field data to quantify and verify existing levels of organic carbon stored in the soil at the time of sampling and can be used to monitor net increases in organic carbon that are added over a specific time period. This method of verification and monitoring has proven to be a statistically superior means of evaluating changes in soil carbon levels.

The direct method of inventory uses GPS to record permanent sample locations or benchmarks. Sample locations must be subject to the same management practices as the rest of the project area. All areas within a carbon sequestration project that are subject to management practices that induce substantial changes in organic carbon over the project life should be verified and quantified.

Use of the direct inventory method with permanent sample locations has two main advantages for carbon monitoring and measurement:

- It provides more reliable data on trends in vegetation development.

- It is more easily verified than other methods, since permanent sample locations can be revisited and remeasured by an external verifier.

Effects of Product End Use

The long-term effectiveness of terrestrial carbon sequestration as a greenhouse gas mitigation strategy depends in part on the end uses of carbon-storing products resulting from project activities and future soil management. Carbon stored in vegetative matter is not stored permanently; organic compounds eventually decay, and some will ultimately be rereleased. Stored SOC is found in the stable humic and fulvic acid soil components, which are resistant to short-term temporal change and have permanence in soils. The impacts of carbon sinks are directly proportional to the “tons/year” of storage and these products can be used to evaluate permanence of storage. Anticipated disposition of biomass can be documented and recorded in the report.

Inventory Outputs

Carbon inventories of land use projects provide two types of information:

- Baseline reports that describe the size, land uses, and ownerships of a carbon sink at the beginning of the project.

- Periodic carbon inventory reports that document changes in the quantities of carbon sequestered/emitted as a result of project activities over time.

The initial baseline carbon report documents the initial quantity and distribution of carbon in vegetation and soils. This baseline is produced before project activities begin and serves as the benchmark from which future changes in carbon stocks are calculated. The baseline report is produced only once per site.

Periodic inventory reports based on monitoring and measurement of permanent sample locations provide the basis for determining changes in carbon sequestered. These reports describe measured quantities and distribution of organic carbon pools in soils and vegetation and calculate the net carbon stored by project activities.

MEASURING CARBON SINKS

Carbon inventories verify and document changes in SOC through time, providing a comparison of preproject SOC levels with later stock changes. To ensure these verifications can be usefully compared to each other, it is important for the inventory to be consistent and utilize a single protocol of measurement techniques and methods between different sites, land uses, and inventory periods.

In addition to monitoring changes in soil carbon, the following components can also be inventoried if desired or required:

- Aboveground biomass
- Belowground biomass
- Standing crop litter

Field Inventory Design

Field inventory designs for on-site carbon inventories are described as follows.

Sampling Design

Sampling designs used in a terrestrial carbon sequestration project must involve the direct method for inventories and monitoring procedures in order to provide the most reliable data.

The value of a set of measurements depends on effective and consistent sampling procedures. Every soil sample should represent a defined body or class of soil. A body or class of soil is a morphologically defined soil horizon or stratigraphic layer with clearly defined dimensions. Soil carbon measurements will have long-term value if they have an associated permanent sampling site and a soil profile description that conforms to standards described in North Dakota State University (NDSU) Extension Bulletin No. SF-990 (revised) (Franzen and Cihacek, 1998) and the U.S. Department of Agriculture (USDA) Natural Resources Conservation Service Fieldbook for Describing and Sampling Soils, Version 2.0 (U.S. Department of Agriculture natural Resources and Conservation Service, 2002). Care must be taken to account for major differences in soil texture. Generally, coarse-textured soils have higher bulk density, and fine-textured soils have lower bulk density. Soil texture greatly influences both the soil bulk density values and the carbon storage values of the soil.

The direct method of permanent sampling sites yields more precise data and information than the indirect method of estimation. In the direct method, each sampling site represents a defined body or class of soil. The identification of features such as vegetation, soils, geological features, topography, and past or present land uses that influence the amount of carbon sequestration is noted at each site.

Useful tools for defining permanent sampling site locations in carbon sequestration areas include satellite images, aerial photographs, vegetation maps, soil surveys, geological surveys, and topography maps. The key to useful sample site locations is to ensure that they are selected by a trained soil scientist or soil classifier who can document the rationale for the sample site as a stable part of the landscape.

To simplify sampling design and understand the precision levels presented in an inventory, sample numbers for each carbon sequestration project should be determined separately, as described in the following section.

Sample Size

The level of precision required for a carbon inventory has a direct effect on inventory costs and, as noted earlier, needs to be carefully chosen by soil scientists who will verify the amounts of carbon in an inventory report.

Sample sizes are determined by the number of acres, landscapes, soil-mapping units, soil types, and their relative location to each other. Most sample sizes are determined on the basis of 160 acres of land (a quarter section) and can be located using standard legal descriptions and plat information. For example, a minimum number of 16 permanent sample sites must be used for each sample size of 160 acres, while an 80-acre sample area will require eight permanent sample sites. Each sample site will represent approximately ten 10 acres of similar types or classes of soil.

Complex landforms or landscapes may require a higher density of sampling sites. Each sampling site is analyzed individually.

Each sample site becomes a permanent sampling plot. Permanent plots will be located utilizing a GPS so they can be relocated to ensure the minimum precision requirements for sampling will be met in subsequent inventories. Plot locations are selected systematically by soil type and landscape.

Collection of Soil Samples

Soils are core-sampled for the initial and final sampling event. Core samples are taken from the adjacent area surrounding the permanent points for laboratory analyses. Five to seven soil sample cores are collected within a 5-meter radius of the permanent point to characterize each sampling site (Figure 1). Soils should be sampled to an overall depth of 12 inches or 30 cm, for the first and final sampling periods during monitoring and verification. The sampling is completed in two stages: first stage of sampling to a depth of 6 inches and second stage of sampling to a depth of 12 inches (the five to seven cores are composited separately for each sampling depth and thoroughly mixed in a field moist condition). A subsample will then be obtained from each composited sample for moisture content analysis in the laboratory when conducting soil bulk density determinations. Carbon- or petroleum-based soil sampling tube lubricants should be avoided because residue from lubricants may contaminate the soil sample and give erroneous soil carbon values.

Soil samples collected for periods between the initial and final samplings of the monitoring period are sampled, at a minimum, to a depth of 6 inches and handled as described above.

The bulk soil sample collected from each permanent soil-sampling site is collected in a plastic container, hand-crushed, and thoroughly mixed for a moisture content subsample. A volume of 1 pint of each soil sample is submitted to the laboratory for analysis (as required by most soil-testing laboratories).

Personnel handling soils should wear laboratory safety gloves for their protection while working with soils.

Soil Moisture (water) Determination

From each plot sample, approximately 30–50 grams of a hand-crushed, mixed, field-moist soil subsample is collected in a preweighed steel or aluminum container with a sealing lid.

When collecting the soil subsample, the lid will be placed on the container in the field to prevent drying of the soil before it can be weighed in the laboratory. In the laboratory, the container, lid, and moist soil will be weighed. After the initial weighing, the lid will be removed and the container with the soil subsample will be placed in a drying oven at 105°C (221°F) for a minimum of 48 hours. Subsamples and containers are then placed into a desiccator containing a drying agent until cooled. The lids are placed back on the containers after cooling. Containers and dried subsamples are weighed again. A weighing balance with a ±0.01-gram accuracy is recommended for completing the weighing determinations. The moisture (water) content is calculated as follows (Gardner, 1986):

$$\text{Water Content Fraction} = \frac{(\text{Mass of Wet Soil}) - (\text{Container Mass})}{(\text{Mass of Dry Soil}) - (\text{Container Mass})} - 1$$

$$= \frac{\text{Mass of Wet Soil}}{\text{Mass of Dry Soil}} - 1$$

The soil is then corrected for moisture for the bulk density determination as follows:

$$1.0 - \text{Water Content Fraction} = \text{Dry Soil Fraction}$$

The calculations should be carried to at least three places after the decimal point. This value is then used in the calculation of soil bulk density.

Soil Bulk Density

Soil samples using the core-sampling method will also be collected for bulk density determinations. Soil bulk density determination follows the core method procedure described by Blake and Hartge (1986), with modifications similar to those of Doran and Mielke (1984). The Soil Science Department at NDSU has determined that a standard soil-sampling tube found on most hand-soil-sampling probes provides results as accurate as the procedure described by Doran and Mielke (1984) (Cihacek and Foss, unpublished). Calculation of soil bulk density is as follows:

Soil Core Cross-Sectional Area × Soil Core Height = Soil Core Volume

The soil core cross-sectional area is determined by the formula πr^2, or $(\pi d^2)/4$, where $\pi = 3.1416$, r = soil core radius, or d = soil core diameter.

Number of Soil Cores per Sample × Soil Core Volume = Total Soil Volume

Mass of Total Soil Volume (as collected in the field) × Dry Soil Fraction = Dry Soil Weight

(Note: Dry soil fraction is obtained from moisture determination.)

In order to obtain the most accurate data, all measurements should be taken as metric units (e.g., centimeters and grams). This allows for final stored soil carbon values to be converted from metric to English units.

Soil Sample Processing

The soil-testing laboratory will air-dry and mechanically crush the entire volume of each composite bulk soil sample. Then, a 10–15-gram subsample is weighed out from the soil sample after it has been completely mixed. The subsample is ground or milled to pass through a 100-mesh (0.15-mm) screen. This subsample is used for the carbon analysis.

It is very important that the entire soil subsample be ground to avoid biasing the analysis as a result of incomplete grinding.

Soil Analysis for Carbon

All soil samples submitted to the soil-testing laboratories are analyzed for carbon by the high-temperature combustion (900°–1000°C) method. This method determines the total carbon (TC) present in the soil sample. The value received from high-temperature combustion is corrected for levels of carbonates or inorganic carbon (IC) when carbonates naturally occur in the soil (soil pH ≥ 7.0). Organic carbon (OC) is determined by the difference between the TC value and the IC value as follows:

$$OC = TC - IC$$

IC is determined by one of three methods: manometric, volumetric, or direct means using acid dissolution of carbonates (Loeppert and Suarez, 1996). IC is subtracted from TC values to determine SOC values. All values obtained for TC, IC, and OC at this point will be in percent (%) carbon mass for the area sampled (see Appendix A).

LABORATORY SELECTION

Laboratories are selected based on their ability to perform high-temperature combustion analysis of soil carbon. Selection of a laboratory will be based on the following:

- Laboratory's main function is as a soil-testing laboratory.

- Laboratory's suitability is determined by the following:

  - Laboratory is certified by the state within which it operates if that state has a certification program, or

  - In states without a laboratory certification program, the laboratory is an active participant in the North American Proficiency Testing (NAPT) Program or similarly accepted soil-testing laboratory proficiency testing program and demonstrates a proficiency of being able to analyze for carbon within the program's accepted mean average deviation (MAD) of the values obtained for the most recent sample exchange conducted by the NAPT Program. If the laboratory does not participate in a certification program, then it must demonstrate that it will become a participant in a certification program within the next sample exchange period.

- The same laboratory that conducts the initial analysis will be used throughout the contract period to provide analytical consistency from one monitoring period to the next.

- In order to maintain quality control, a soil check sample of known carbon content (a previously analyzed NAPT soil sample) will be analyzed after every 15th soil sample. One out of every 35 samples is submitted to another suitable laboratory based on the above criteria as an outside check on a laboratory's quality control.

SAMPLE ARCHIVING

Soil monitoring will occur over a period of several years. Because of the possibility that laboratories may change their function or cease operation during the contract period, samples from the initial sampling of each field will be archived as reference samples. This provides a valid reference for resolving any possible discrepancies.

A minimum of 50 grams of air-dried soil should be archived in a sealed, waterproof, and air-tight rigid plastic or glass container to prevent damage by moisture, rodents, or insects and contamination by other materials. Samples should be stored at room temperature (70°F, or 21°C) or cooler.

REPORTING RESULTS

The estimation of carbon sequestered in the soil will be reported as tons (US) per acre per soil depth sampled or megagrams (or metric tons) per hectare per soil depth sampled. Care must be taken that the proper conversion of values occurs and that the units reported at each verification period are the same as reported for the previous period. Conversion equivalencies are found in Appendix B.

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APPENDIX A

CARBON MASS CALCULATION

CARBON MASS CALCULATION

Calculations of carbon mass in soil begin with a % organic carbon value and a bulk density value.

Initial assumptions:

Bulk density is generally calculated as grams per cubic centimeter, or g/cm^3.

A soil core that is 6 inches long is a soil column that is 15.2 cm long.

A square meter is 100 cm long on a side or 10,000 square cm^2 in area.

One hectare (ha) is 100 meters (m) long on a side, or 10,000 m^2 in area.

One acre is 0.405 ha.

Therefore:

Bulk density (g/cm^3) × 15.2 × %C in sample = C mass (g) for a column 1 cm^2 and 6 inches long.

C mass for 1 cm^2 column × 10,000 = C mass for 1 m^2

C mass for 1 m^2/1000 = kg C per m^2

kg C per m^2 × 10,000 = kg C per ha

kg C per ha/1000 = Mg C per ha

Mg C per ha × 0.405 = Mg C per acre (A)

APPENDIX B

CONVERSION FACTORS

CONVERSION FACTORS

Temperature:

°F = (9/5°C) + 32
°C = (5/9°F) − 32

Area:

Hectares = 2.47 acres
Acres = 0.405 hectares

Distance/length:
1 inch = 25.4 millimeters
1 inch = 2.54 centimeters
1 millimeter = 0.03937 inches
1 centimeter = 0.3937 inches

Mass/weight:

1 gram (g) = 0.0022 pounds (lb)
1 pound = 454 grams
1 kilogram (kg) = 2.205 pounds
1 pound = 0.454 kilograms
1 ton (US) (t) = 2000 pounds
1 tonne (metric) (mt) = 2204 pounds
1 tonne (mt) = 1000 kilograms
1 megagram (Mg) = 1 tonne (mt)
1 megagram = 1000 kilograms
1 megagram = 2204 pounds
1 ton (US) = 907 kilograms
1 ton (US) = 0.907 megagrams
1 ton (US) = 0.907 tonne

Yield/rate

1 pound per acre = 0.893 kilogram per hectare
1 kilogram per hectare = 1.12 pounds per acre
1 tonne per hectare = 1 megagram per hectare = 893 pounds per acre
1 megagram per hectare = 1 tonne per hectare = 0.446 tons (US) per acre
1 ton (US) per acre = 2.24 megagrams per hectare

Carbon equivalencies:

1 ton of CO_2 = 0.2727 tons of soil carbon
1 ton of soil carbon = 3.667 tons of CO_2