Terrestrial Carbon Sequestration

Field Guide for Sampling and Analysis for Sites Remediated with Soil Amendments

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FOREWORD

The U.S. Environmental Protection Agency (EPA)'s Technology Innovation and Field Services Division developed this field guide to provide a consistent sampling approach across sites being analyzed for terrestrial carbon sequestration. EPA wants to partner with other federal, state, tribal, and local agencies, academia, and other interested parties to build our knowledge of terrestrial carbon sequestration rates. This field guide was developed so that EPA and other researchers use consistent approaches to plan and implement field efforts, allowing for data comparison and research collaboration. This field guide focuses on a methodology to provide data that can be used in mathematical equations and models to determine terrestrial carbon sequestration rates in soil. Equations in this guide focus on use of carbon data, but the approach provides for a range of parameters that can be used for related carbon sequestration analyses.

This field guide is also a first step in assessing the potential of terrestrial carbon sequestration at sites remediated and revitalized using soil amendments. Soil amendments are residuals from industry that provide positive change in chemical, physical and biological properties of disturbed soil. For more information on soil amendments refer to EPA's document "The Use of Soil Amendments for Remediation, Revitalization, and Reuse" EPA 542-R-07-013.

This field guide is a living document to be updated as we learn more about terrestrial carbon sequestration and improved data collection and analytical methods. This document was field tested through a pilot study at three different contaminated sites across the country. This is Version 1 and is based on our data collection approach at those sites. EPA shares information on terrestrial carbon sequestration at www.cluin.org/ecotools . We plan to conduct more field analysis on terrestrial carbon sequestration and host this information in a searchable format. Future work in this area includes: public presentations, internet trainings, scoping exercises for determining carbon balance and the additionality and permanence of terrestrial carbon sequestration at our sites, additional site analysis, and collaboration with others interested in this topic. EPA leads for this effort are Harry Compton, Michele Mahoney, and Ellen Rubin.

EPA is actively looking for partners in this effort. To join us or learn more, please contact Michele Mahoney, 703-603-9057, mahoney.michele@epa.gov.

DISCLAIMER: This field guide offers technical information for EPA, State, and other representatives that may wish to implement field sampling and analysis activities to estimate terrestrial carbon sequestration at sites remediated with soil amendments. The information is intended as a guide for planning and implementing field work and sample analysis to support such studies; parties can use the information in developing site-specific approaches that are appropriate for site-specific needs. This document may reference technologies and processes used by outside parties and which have been applied for a pilot project implemented by EPA. Mention of specific technologies and processes does not imply endorsement for specific purposes.

This guide is not a regulation; therefore, it does not impose legally binding requirements on the EPA, States, or the regulated community. It may not apply to all situations. EPA, States, and personnel may use other approaches, activities, and considerations either of their own or at the suggestion of interested parties. Interested parties are free to raise questions and objections regarding this document and the appropriateness of the approaches and recommendations in a particular situation for EPA to consider. This guide is a living document and may be revised periodically without public notice. EPA welcomes public comments on the document for consideration in future revisions of the document.

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Introduction

Thousands of acres of Superfund, Brownfields, and mining sites, as well as landfills and industrial properties with contaminated or disturbed soils, exhibit a variety of problems that often can be addressed effectively and directly using soil amendments (EPA, 2007). Soil amendments are generally by-products from other processes that have beneficial properties when added to soil. Commonly used amendments include municipal biosolids, animal manures and bedding, sugar beet lime, wood ash, log yard waste, neutralizing lime products, and composted organic materials including yard trimmings, food scraps, biosolids, and a variety of agricultural byproducts. When contaminants are present at sites, soil amendments may reduce the risks associated with contaminants by limiting exposure pathways and chemically changing or immobilizing contaminants. This may also reduce the bioavailability of the contaminants and allow for ecosystem restoration at these sites. The addition of amendments may also restore soil quality by balancing pH, adding organic matter, increasing water holding capacity, re-establishing microbial communities, and alleviating compaction. As such, the use of soil amendments enables site remediation, revegetation, and reuse.

In addition to the environmental benefits of using carbon rich soil amendments for remediation and restoration, additional co-benefits may be achieved through terrestrial carbon sequestration. Terrestrial carbon sequestration in this context is defined as the enhanced removal of carbon dioxide (CO_2) from the atmosphere through accelerated carbon storage in soil. In addition, applying carbon-rich soil amendments to contaminated sites provides a high concentration of carbon to low carbon soils and thereby, an improved environment for plant growth. The underlying premise of building soil organic matter and re-vegetating as a climate change mitigation strategy is that healthy soils store carbon and support plant growth, which can remove more CO_2 from the atmosphere than existing carbon-poor, barren lands containing no soil organic matter and supporting limited or no vegetation (EPA, 2009a). In some cases, remediation with soil amendments may also provide other emission-avoidance type of benefits (e.g., landfill disposal avoidance of the by-products that are used as amendments results in avoidance of methane (CH_4) emissions from these products in a landfill).

This field guide was designed as a general approach to plan and implement the collection of sampling data to yield site-specific estimates for a number of factors that can be used in equations, carbon accounting models, and other tools to determine carbon sequestration results. These efforts assist in testing the hypothesis that using organic amendments to remediate contaminated sites creates a carbon-rich “soil” that leads to carbon sequestration in terms of both “additionality” and “permanence” (Ravindranath and Ostwald, 2008). Additionality is defined as how much of the sequestration is a result of soil amendment application, beyond the estimated sequestration that would occur without the application. Permanence refers to the life span of the sequestered carbon; that is, whether the additional carbon sequestered at a site can be considered long-term or permanent with a low potential for later release or re-emission. This guide is intended for use at contaminated sites where soil amendments have already been applied (past remediation activities) and at sites where remediation is planned or currently in progress.

This field guide focuses on field methods and approaches to collect data to support documentation of carbon sequestration potential and results. EPA recommends that the user first gain a background understanding of the subject matter (terrestrial carbon sequestration at sites remediated with soil amendments) to inform site-specific hypothesis development and implementation of this guide's approach. Background documents for further study are identified on EPA's webpage (http://cluin.org/ecotools/seq.cfm) and in this document's reference section.

This field guide provides a general technical approach to collect data to support the evaluation of terrestrial carbon sequestration at remediated sites, such that project teams can partner with EPA to build a new knowledge base for carbon sequestration upon comparable data sets.

The types and amounts of field data collected in support of a carbon sequestration analysis project should begin with, and be driven by, the identification of the basic hypotheses to be tested during the project, which should be formulated by the project team and other stakeholders. For example, one basic project hypothesis is that soil amendments would result in carbon sequestration benefits at a site (with a given confidence level in the results). Another example hypothesis could be that the selected remedy attains a given level of sequestration within five years, plus or minus 5 percent. After clarifying and agreeing on the site-specific hypothesis to be tested, the project team should review the various carbon accounting models and incorporate data needs into project planning. This guide can help a team identify types of field data needed to properly test a hypothesis and provides reference operating procedures and methods that can support sampling and analysis. The general data collection approach provided in this guide outlines four steps that should be followed to plan and implement the field evaluation. Following management and interpretation of the collected data, the team should evaluate the study and plan future work. The four steps discussed in the remainder of this guide include:

1. **Document Site-Specific Information**

2. **Plan for Data Collection**

3. **Collect and Analyze Data**

4. **Manage and Interpret Data**

The Appendices of this document provide background information, literature references, and suggested standard operating procedures (SOPs) for sample collection and analysis. Data from the sampling and analytical approach presented in this field guide are intended for application in carbon sequestration equations and carbon accounting models and other tools such as the "Carbon Sequestration Estimation Calculation Methodology for Soil Amendment/Re-vegetation Remediation" (EPA, 2009a) and "Carbon Inventory Method"(Ravindranath and Ostwald, 2008).

<u>Step 1. Document Site-Specific Information</u>

Background or baseline information about the site is pertinent to fully document site characteristics and evaluate carbon sequestration potential and results. Some of the site information listed below is required for the carbon sequestration equations included in the text of this field guide (Step 4). Other site information listed below may be used for calculating other aspects of carbon sequestration potential and results (using carbon accounting protocols and models); the recommended information also provides useful background information and data to compare results across sites over time. Compile and document the following:

- Site Name
- Site Location (city/state, geographic positioning system [GPS] coordinates)
- Site Owner(s)/Responsible Party(ies)
- Site Area and Surface/Subsurface Features, including soil type and geology
- General Site Description and History (include date ranges for all human activities)
- Map(s)
- Past, Current, and Future Site Use(s)
- Land Uses and Activities Surrounding the Site
- Properties of Native and Contaminated Soils (including chemical, geological, and geotechnical data, as available) and Waste
- Environmental Receptors
- Site Slope and Watershed
- Leaching and Runoff Potential
- Nature of Amendment(s), including origin, composition, analytical data, regulatory status/disposition, treatability studies (e.g., is it a waste?)
- Alternate Amendment Management (that is, how would the material be used, managed, or disposed if not used as a soil amendment?)
- Date(s) of Amendment Application
- Amendment Application Rate (dry weight)/Amount and Depth
- Rationale for Selected Amendment (e.g., local availability, to support stabilization of metals or other waste constituents, etc.)
- Regulations Covering Amendment Application
- Equipment and Methods Used for Amendment Transportation and Application (including estimates of fuel and energy use)
- Site Operation and Maintenance (O&M) Activities (including estimates of fuel and energy use, and of vehicle miles traveled)
- Climatic Variables for Site, including monthly temperature (range and average temperatures), as well as monthly total precipitation
- Vegetation Types (on-site and surrounding area)
- Community Relations

A suggested format for recording site information and site reference documents is presented in Appendix 1, Suggested Format for Site Information. EPA recommends that users confirm the specific data elements required for intended site-specific project goals, as part of Step 2.

Step 2. Plan for Data Collection

Project planning activities should follow “EPA Requirements for Quality Assurance Project Plans” (EPA, 2002a) and include input from all stakeholders responsible for major project elements, such as sampling, analysis, data management, quality assurance, and data interpretation/application. Particular attention should be paid to establishing appropriate data quality objectives (EPA, 2006). The project team should include personnel familiar with the site through on-site work or visits so that the effects of site conditions or constraints on the sampling design, procedures, and logistics can be adequately assessed. In addition to a sampling and analytical strategy, the planning process should identify any additional data needs for accurate carbon accounting, such as information concerning on-site carbon emission sources or other gaps in the site information compiled in Step 1. Data needs and inputs are further discussed in EPA’s working draft “Carbon Sequestration Estimation Calculation Methodology for Soil Amendment/Re-vegetation Remediation” (EPA, 2009a). The planning process should also identify the statistical data reduction methods and carbon accounting tools to be applied following the field program so that any associated data requirements are identified and incorporated into the sampling program.

Outcomes from the above activities should be documented in a quality assurance project plan (QAPP) to specify sampling, analytical, and quality assurance/quality control (QA/QC) procedures for data collection at the site. The QAPP should be written in accordance with the applicable EPA and/or Uniform Federal Policy (UFP) requirements (EPA, 2002a; EPA, 2005). The QAPP and a Health and Safety Plan should document any hazards associated with soils or soil amendments sampled during the field program, so that: (1) sampling and laboratory personnel can adopt appropriate safety procedures, and (2) investigation-derived waste (IDW) can be properly disposed (minimization of IDW should also be addressed during project planning).

The QAPP should include a site-specific statistical sampling strategy for the site. Available EPA guidance (EPA, 2002a; EPA, 2002b) or a statistician can be consulted to assist in devising the sampling design. Appendix 2 provides an example sampling approach for consideration; this approach is based on a pilot study that was implemented at three sites (EPA, 2010c).

The QAPP provides details on the technical approach for characterization of soil amendments, soil (reference and treated), and biomass at the site. Recommended analytical parameters and methods are presented in Table 1. For sites where the sampling program is initiated at the time of amendment application, multiple sampling events are recommended over time as outlined in Table 2, beginning with a baseline (or “Time 0”) sampling event performed before the amendments are applied. At sites that are sampled after amendments have been applied and are in place, fewer sampling events than those listed in Table 2 may be needed to adequately assess carbon sequestration (because these sites may be approaching asymptotic or equilibrium conditions). The number of sampling events needed in these cases should be carefully considered by the project team.

Step 3. Collect and Analyze Samples

The sampling and analytical approach should be consistent across the different sampling events at a site in regard to numbers and types of samples, sample depths, collection and management approaches, analytical parameters, and methods. Additional considerations and recommendations regarding sample collection and analysis are presented below.

Soil Amendments: If sufficient existing data were not identified for the soil amendments during Steps 1 and 2, EPA recommends to collect three to five composite samples per batch mix of soil amendment (or as directed by the sampling strategy developed as part of Step 2). Analyze samples for total carbon and nitrogen using high-temperature combustion methods (see Appendix 3) (EPA, 1998). Determine inorganic/organic carbon fractionation using acid vapor exposure (see Appendix 4) (Harris et. al., 2001). Analysis of soil amendments may not be possible for sites that are sampled long after the amendments have been applied. In these cases, soil amendment information may be available in remedial design or construction completion documentation, or through the vendor or provider of the by-product materials used.

Soil: Soil sampling identifies characteristics of reference and treated soil. Collect composite samples of soil in accordance with the QAPP (Appendix 2 recommends the collection of three to five composite samples at random locations within each treatment plot or other designated area evaluation unit under the QAPP, with each sample consisting of a 4-point composite). The sample increments should be collected via coring techniques from a minimum of two depth intervals at each location, 0-15 centimeters (cm) and 15-30 cm, unless site conditions or settling dictate alternate soil depths. The four shallow depth samples and four deeper depth samples from each location can be composited separately for analysis by depth, providing one composite sample from each depth interval for each sampling location. The need for deeper core intervals should be assessed by the project team during the planning process. As noted previously, alternate depths for sampling may be required based on site conditions, such as shallow soils over bedrock or natural soil conditions which control soil horizon development.

The location of each sample core should be geo-referenced with a GPS unit. In addition to amended soil from treatment plots (treated soil), sampling includes un-amended soil from control or reference areas (reference soil), as appropriate. Reference areas consist of untreated on-site soils or wastes that are similar to the materials (contaminated soils or wastes) that are being amended. Note that general information on U.S. soils, including soil chemistry data, is available on the Natural Resources Conservation Service (NRCS) Web Soil Survey Web site (USDA, 2010): http://websoilsurvey.nrcs.usda.gov/app/WebSoilSurvey.aspx.

In addition to the geochemical and physical analyses of soil (i.e., pH, electric conductivity [EC], soil texture, and bulk density) at contaminated sites, measuring total carbon and nitrogen using high-temperature combustion methods is recommended (Appendix 3), along with inorganic/organic carbon fractionation using acid vapor exposure (Appendix 4) as needed for soils with a pH greater than 6.8. In addition, soil samples from coal mining sites need to differentiate between existing (native) and new (added by amendments) carbon. One method option for the differentiation of coal-based carbon is included in Appendix 4 (Ussiri and Lal, 2008). However, this method may not be applicable for all types of coal; methods for accurate assessment of carbon at coal sites are still being developed and evaluated.

The preferred method for determination of bulk density is collecting and weighing intact soil cores in accordance with Appendix 5 (USDA, 2004). At sites where the collection of intact soil cores is not possible, bulk density can be estimated in the field through volume replacement techniques (that is, a small excavation of soil, lined with a plastic bag, where the excavated area is lined and filled with water, after which the volume of water is measured). Alternatively, soil bulk density can be determined in a laboratory as the ratio of the mass of dry soil per unit volume. For this method, a vessel of known volume is filled with a moist field sample. The soil is then thoroughly dried at 105ºC and weighed.

The bulk density procedure selected should be identified in the QAPP and consistently and carefully applied for all samples to ensure that the bulk density results are as accurate and representative as possible. This is important because errors in bulk density results can significantly affect the accuracy of carbon accounting activities.

Biomass (if present): Separate organic matter from soil samples to estimate above- and below-ground biomass. Example methods for biomass are presented for consideration in Appendix 6 (EPA, 1994; EPA, 2004).

Gases: Analysis of air for greenhouse gases is recommended only for sites where amendments are currently being applied. At such sites, monitoring of nitrous oxide, CO_2, and CH_4 emissions is recommended for up to one month immediately following amendment application. These data allow for more accurate adjustments of initial carbon sequestration rates for emissions associated with the remediation process. Suggested methods are included in Appendix 7 (USDA, 2003), and other air monitoring references are provided for consideration (Hao et. al., 2001; Hedley et. al., 2006; Mosier and Klemedtsson, 1994; Pennsylvania Department of Environmental Protection, 2006). Note that based on agricultural guidance (i.e., fertilizer application) from the International Panel on Climate Change (IPCC), nitrous oxide emissions can be estimated as approximately 1% of the total nitrogen applied at a site (IPCC, 2006).

Soil Amendment Application Method: Sampling programs that are performed as part of current or ongoing remediation programs should document the methods and equipment used for amendment application in the field (i.e., manure spreader, tillage, etc.). This documentation should include fuel consumption during amendment transport and application. Standard deductions for fuel consumption are available in other EPA guidance (EPA, 2009b; EPA, 2010a; EPA, 2010b). This assists in life-cycle analyses of emissions associated with a remedial approach.

Operation and Maintenance: Follow-on sampling events should document equipment and procedures used for O&M activities at the site, including fuel use. Again, these data may be used for life-cycle carbon accounting evaluations. The project team should assess whether archiving of biomass or soil samples (e.g., freezing and storing samples for further testing or for direct physical comparisons between sampling events) is necessary or appropriate.

Step 4. Manage and Interpret Data

Data management protocols are to be determined by the site-specific study goals and the carbon accounting tools or models to be employed. An example data reduction and analysis protocol for carbon sequestration has been referenced previously (EPA, 2009a). The selected carbon accounting approach should include well-defined algorithms to assess carbon sequestration additionality and permanence as defined in the introduction to this field guide. Suggested fields for the selected data management approach (e.g., database) include, but are not limited to: sample identification and GPS coordinates, sampling dates, sampling methods, analytical methods, carbon in each medium at each time measurement; carbon delta (increase or decrease in carbon mass relative to baseline); CO_2 equivalents; application rate; method of application; weather data; analytical results for all media (e.g., biomass, soil physical and chemical properties, amendment physical and chemical properties, gas results); analytical detection limits (as applicable); reporting units (soil) or other data reporting protocols (e.g., for biomass; see Appendix 6) (EPA, 2009a).

Carbon results are generally reported in metric tons of CO_2 equivalents and compared to reference sample data to determine carbon additionality potential. Equations for conversion of carbon (C) results to CO_2 equivalents (Tian, et. al., 2009) are as follows:

$$\frac{\%C}{100} \times BD \times AD \times \frac{10{,}000\ m^2}{ha} = \text{Mg C per ha}$$

Where: % C = Mean percent carbon content of amended soil over the depth interval and treatment unit of interest
BD = Mean bulk density (in Mg/m^3)
AD = Amended soil depth interval of interest (in m)
m = meters
Mg = megagrams (metric tons)
ha = hectare

Conversion to CO_2 equivalents in Mg (metric tons) per hectare:

$$\frac{\text{Mg C}}{\text{ha}} \times \frac{44\ \text{g/mole}\ CO_2}{12\ \text{g/mole C}} = \frac{\text{Mg}\ CO_2}{\text{ha}}$$

The above calculation for CO_2 equivalents can be applied to soil, amended soil, or soil amendments, and is central in the evaluation of terrestrial carbon sequestration. Based on other parameters specified in Table 1 and other information collected for the site under Steps 1 and 3 above, estimates of carbon sequestration associated with other site media (such as site biomass), and releases associated with site activities (including remediation) can also be developed to calculate a net CO_2 equivalent value for the site. Qualitative or quantitative comparisons of CO_2 equivalents between treated areas and reference areas (also called "business as usual" [BAU] areas) allow for the evaluation of carbon sequestration additionality. Evaluations of multiple sampling events over time allow for the evaluation of permanence. Given the developing nature of this field, approaches to additionality and permanence continue to develop. As part of Step 1, the site-specific hypothesis and boundaries desired for carbon sequestration analysis should be identified at the start of each project's planning.

Further data reduction guidance or calculation protocols are not provided in this field guide for the other analytical parameters listed in Table 1. Instead, this field guide focuses on identifying the parameters generally required for a complete analysis and provides a step-wise approach for site planning, field work, and analysis to obtain the data needed. The full suite of parameters identified in Table 1 are generally used for other evaluations associated with carbon cycling and sinks at a site (e.g., inorganic carbon and soil physical characteristics) as well as accounting for emissions of other greenhouse gases (e.g., nitrogen oxides, CH_4) as part of life-cycle carbon accounting efforts. The reader is again referred to other more comprehensive introductions to carbon and greenhouse gas accounting for more information (EPA, 2009a; Ravindranath and Oswald, 2008).

Pilot Application of the Field Guide

The steps and methods identified in this field guide have been implemented as part of a pilot study at the following sites in order to test the hypothesis that soil amendments enhance carbon sequestration:

- California Gulch Superfund Site, Leadville, CO – a mine tailings site where soil remediation using biosolids (wood chips, fish pond sediments, and municipal biosolids) and lime was completed in 1998.
- Stafford Airport Site, Stafford, VA – an acid rock drainage site where soil was treated with lime and lime-stabilized biosolids (compost, straw mulch, and municipal biomass) in 2002.
- Sharon Steel Superfund Site, Farrel, PA – a former steel works where treatment of slag and sludge with municipal biosolids and a range of other additives (wood chips, bark, and compost) was being initiated at the time the pilot study began (test treatment areas were installed in September 2008).

This pilot study is documented in a report titled "Analysis of Terrestrial Carbon Sequestration at Three Contaminated Sites Remediated and Revitalized with Soil Amendments" (EPA, 2010c).

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Table 1. Analytical Measurements for Soil Amendments, Cores, Gases, and Plants (Biomass)

Matrix	Analyses	Method(s)	Reference(s)
Amend-ments	Total Carbon Inorganic/Organic Carbon Fractionation Total Nitrogen Organic Matter Content Moisture Content pH Electrical Conductivity (EC)	Dry flash combustion Acid vapor exposure Dry flash combustion Loss on ignition Thermal-gravimetry Paste-electrode Paste-electrode	Appendix 3 [1] Appendix 4 Appendix 3 [2] Nelson et. al. 1996 Gardner 1986 Thomas 1996 Rhoades 1996
Soil	Total Carbon Inorganic/Organic Carbon Fractionation Total Nitrogen Organic Matter Content Moisture Content Particle Size Analysis (sand, silt, clay) Bulk Density pH EC	Dry flash combustion Acid vapor exposure Dry flash combustion Loss on ignition Thermal-gravimetry Sieving-gravimetry Gravimetry Paste-electrode Paste-electrode	Appendix 3 [1] Appendix 4 Appendix 3 [2] Nelson et. al. 1996 Gardner 1986 Gee et. al. 1986 Appendix 5 Thomas 1996 Rhoades 1996
Biomass/ Plants	Above and below ground biomass sampling and estimation (dry weight)	Thermal-gravimetry	Appendix 6
Gases	Nitrous oxide Carbon dioxide Methane	Static flux chamber – headspace gas chromatography (GC)	Appendix 7

Notes:
[1] See also Nelson et. al. 1996.
[2] See also Bremner 1996.

Table 2. Sampling Events

Sampling Event	Matrices[1]	Purpose
Time 0 or before (pretreatment) [2]	Soil amendment; soil	Establish baseline carbon assessment for site
Time 0 or before (pretreatment) [2]	Plant biomass and inventory (if present)	Establish baseline
Time 0 [2]	Amended soil, reference soil	Measure initial carbon
Time 0 [2]	Plant biomass and inventory (if present)	Measure initial biomass
Time 0 [2]	Gases in air [3]	Determine nitrous oxide, carbon dioxide, and methane emissions from amendment for a minimum of one month.
Year 1	Amended soil, reference soil	Assess one-year changes in terrestrial carbon
Year 1	Plant biomass and inventory (if present)	Assess one-year plant growth
Year 3	Amended soil, reference soil	Assess changes in terrestrial carbon
Year 3	Plant biomass and inventory (if present)	Assess changes in biomass
Year 5	Amended soil, reference soil	Assess longer-term changes in terrestrial carbon; determine need for further sampling times
Year 5	Plant biomass and inventory (if present)	Assess longer-term changes in biomass
Year 10	Amended soil, reference soil	Assess longer-term changes in terrestrial carbon; determine need for further sampling times
Year 10	Plant biomass and inventory (if present)	Assess longer-term changes in biomass

1. Matrix Definitions:
   Soil amendment: residual from other processes that improves disturbed soil when applied (such as biosolids, foundry sands, coal combustion products)
   Soil: soil material on site prior to amendment application
   Plant biomass: plant material present, above- and below- ground
   Amended soil: soil material after amendment application
   Gases in air: emissions from treatment plots
   Reference soil: soil material that was not amended and similar in characteristics to original amended soil
2. "Time 0" denotes the baseline sampling event.
3. Measuring gasses in air is difficult; literature values are acceptable by IPCC, 2006.