SOIL SAMPLING PROTOCOL TO CERTIFY THE CHANGES OF ORGANIC CARBON STOCK IN MINERAL SOILS OF EUROPEAN UNION

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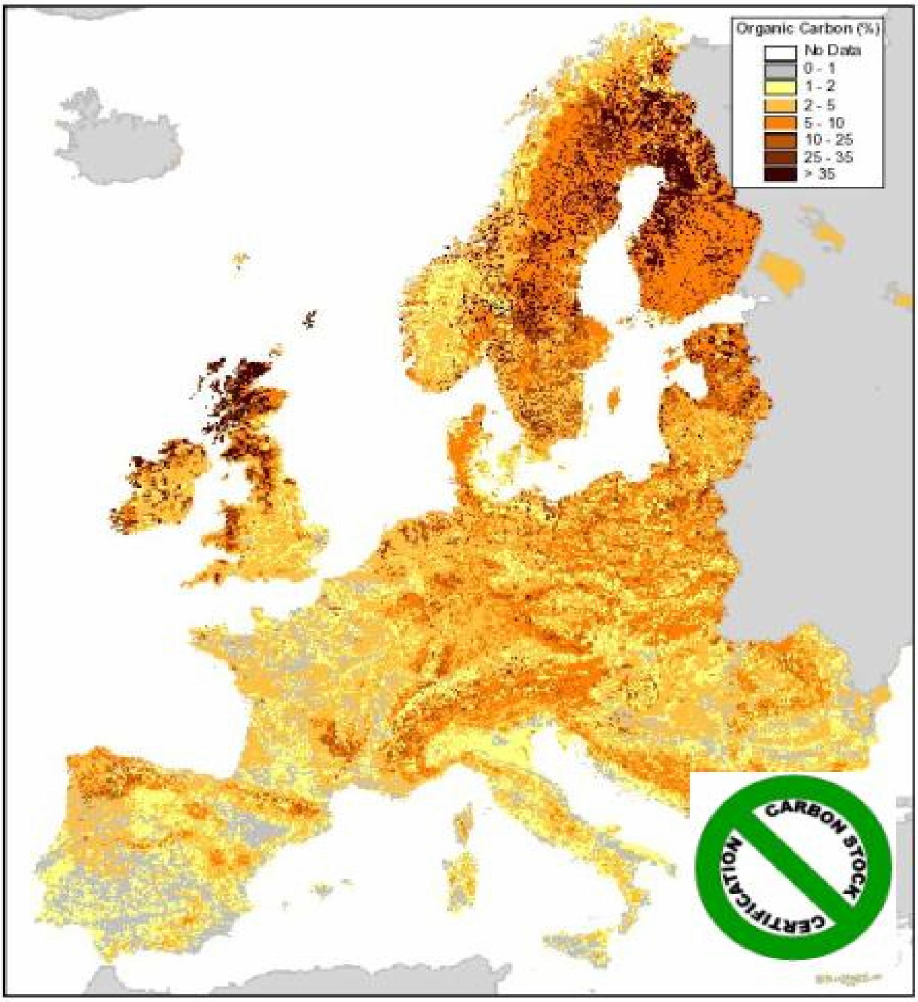
Nicola Filippi, Senthil-Kumar Selvaradjou,
Panos Panagos and Javier Gallego



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Preface

The entry of the Kyoto Protocol into force opens an opportunity for wide scale implementation of land use, land use change and forestry (LULUCF) projects in European Union (EU). These activities are conditioned by a number of rules provided by the Kyoto protocol and complimentary regulations (IPCC 2000, 2003). This study supplements these documents by establishing technical details on the soil sampling at the LULUCF plot level.

This Protocol was developed within Integrated Sink Enhancement Assessment project and the action MOSES - Monitoring the State of European Soils (Soil and Waste Unit, Institute for Environment and Sustainability, Joint Research Centre of the European Commission) to support implementation of the Kyoto Protocol in EU. The European Soil Bureau Network revised the guidance.

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Abbreviations

LULUCF: Land Use, Land-Use Change, and Forestry
EU: European Union
SOC: Soil Organic Carbon
ISO: International Organization for Standardization
SRS: Simple Random Sampling
CRS: Coordinate Reference Systems

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1 Introduction

The Kyoto Protocol (UNFCCC, 1998) considers soils as an essential component to mitigate the increasing concentrations of greenhouse gases in the atmosphere. Two additional reports: (1) Land Use, Land-Use Change, and Forestry (LULUCF) (IPCC, 2000) and (2) Good Practice Guidance for LULUCF (IPCC, 2003) identify soil organic carbon (SOC) monitoring to be an obligatory tool when implementing Articles 3.3 (afforestation, reforestation and deforestation since 1990), and Article 3.4 (forest management, cropland management, grazing land management, revegetation) of the Protocol. However, the general norms provided by these documents do focus on the countrywide SOC accounting and reporting and are insufficient for application in the LULUCF plot exclusively, e.g., agricultural field, pasture or forest. These norms have to be supplemented by practical details that make them operational at the LULUCF plot level. The lack of a reliable method on practical soil sampling to certify the changes of organic carbon stock in soils might be a serious obstacle for implementation of the Kyoto Protocol in EU.

However, there is an urgent need to set out a common soil sampling procedure beyond the Kyoto Protocol. Many soil functions are driven by SOC, e.g, fertility, buffering capacity, adsorption and absorption of chemicals, filtering storing and maintaining water quality, regulation of atmospheric gas composition, etc. Any decline in SOC diminishes soil quality and has been identified as a serious environment threat by European Environment Agency (Huber et al., 2001) and the Soil Communication (EC, 2002). Thus this methodology attempts to contribute to establishing an important common criterion of soil quality in EU, namely SOC.

Soil forms a continuum in space and changes in time. Soil extends in depth and is invisible from the surface. Information on soil can be obtained by observation of a section or profile from which soil samples can be taken. Samples can be collected in different ways and the characteristics of soil resulted from various sampling procedures are different. Consequently, the International Organization for Standardization (ISO) has set up a standard (ISO, 2002) that describes principle rules for designing soil-sampling strategies and the techniques for collecting the samples.

The objective of this report is to design a protocol for soil sampling at the LULUCF plot, which is selected field, pasture or forest plot. The results of the analysis should allow national agents to certify changes in organic carbon stock in soils that can be attributed to LULUCF activities. It includes the following procedures:

- location of sites from which samples should be taken;
- identification of sampling quantity and composition;
- methods of the sample collection;
- algorithms for data acquisition and accuracy control.

2 Standard norms

The guidance follows the general requirements of the International Standard (ISO/FDIS 10381-1:2002(E)). It is particularly relevant to ISO 10381-4 devoted to “Sampling to support legal or regulatory action” that covers the requirements to establish baseline conditions prior to an activity, which might affect the composition or quality of soils.

Sampling strategies included in the protocol are consistent with IPCC LULUCF's good practical guidance, which requests, quality assurance and quality control, data and information to be documented, archived and reported, quantification of uncertainties at the source or sink category level and for the inventory as a whole (IPCC, 2003, p.1.6).

3 Technical specification

3.1 Site location

The location of sampling sites should be fixed in European Coordinate Reference Systems (CRS identifier ERTS89 Ellipsoidal CRS) (Boucher, C., Altamini, Z., 1992). The position should be recorded with the precision of 10m in the field by means of Global Positioning Systems (GPS) to be used for return visits to the sampling site. Data can be downloaded to a portable or office computer for registration and combination with other layers of information for spatial analysis.

The area of the LULUCF plot should be defined by a combination of survey equipment such as theodolites, tape measures, distance wheels and electronic distance measuring devices.

3.1.1 Statistical background

To assist better uniform soil sampling in the LULUCF plots, a sampling template with a randomized point distribution is proposed (Figure 1).

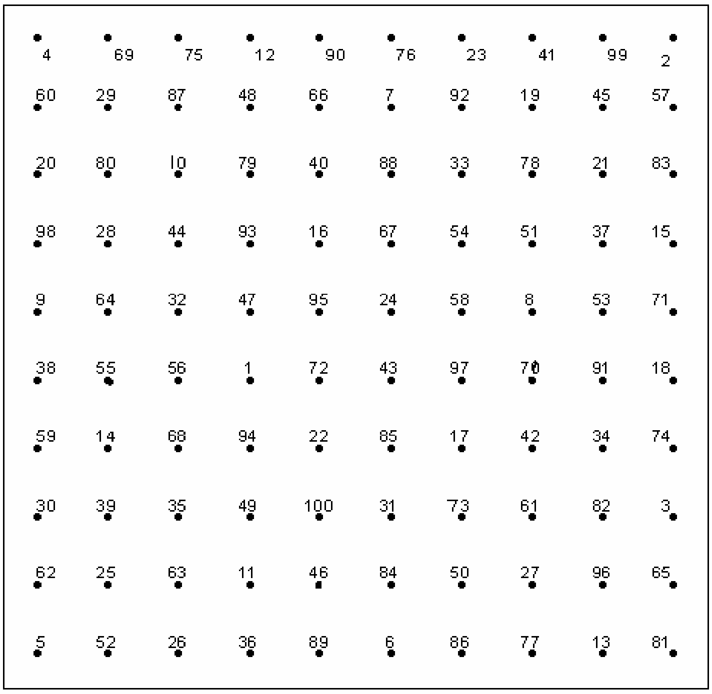

Figure 1. Randomised sampling template for soil sampling

The grid of 100 points (Figure 1) is the result of a 'modified random sampling' with a distance threshold.

Point number 1 was selected at random. Point number 2 was also selected at random, but points at a distance less than 6 ‘distance units’ (the grid step) were forbidden. Where it is not possible to find points more distant than 6 units, the distance threshold is progressively relaxed.

This sampling approach avoids the first sampled points being too close to each other, which would result in partially redundant information. In fact, under the reasonable hypothesis that the correlogram is a decreasing function of the distance, sampling plans that ensure a greater distance between the points in the sample frame, give a lower variance. This occurs for example for systematic sampling, but also for other sampling plans (Bellhouse, 1977, 1988). Systematic sampling, or other sampling plans that avoid points too close to each other, gives a lower variance than simple random sampling (SRS), but the application of the formulae given in the section ‘uncertainty’ to such sampling plans generally overestimates the variance (Wolter, 1984). There are estimators that reduce the bias of the variance estimator, but it is safer to use the ‘conservative’ estimators given above because additional uncertainty can come from non-sampling sources.

3.1.2 Sampling procedure

The method is an area frame sampling. Each area is defined by a cell around a point of a regular grid (Figure 1). In each sampled area a composite sample will be collected following the rules described below. These sampling schemes are based on the following conditions:

- The size of the grid is variable depending on the area of the LULUCF plot.
- Sampling sites encompass profile excavations and areas where composite samples are taken.
- The profiles are used to record soil morphological parameters and take the subsequent samples of undisturbed soil to determine soil bulk density.
- Sampling points are used for collecting samples and identifying coarse fragments. All samples, excluding those of undisturbed soil, are combined in the field to form a composite sample, which is treated in the laboratory as a single field sample for analysis.
- The parameters and location of the sampling scheme should be instrumentally geo-referenced and kept for the re-sampling. In order to reduce disturbance in bulk density measurement for the 2nd sampling the profiles will be located at the 1st top left sampling point of each sampling site; for the 3rd sampling, they will be at the 2nd one, and so on.

In practice, the LULUCF plot will have often irregular form. To derive a better fit of the plot with the randomized template the geographical coordinates of the latter have to be involved (Figure 2).

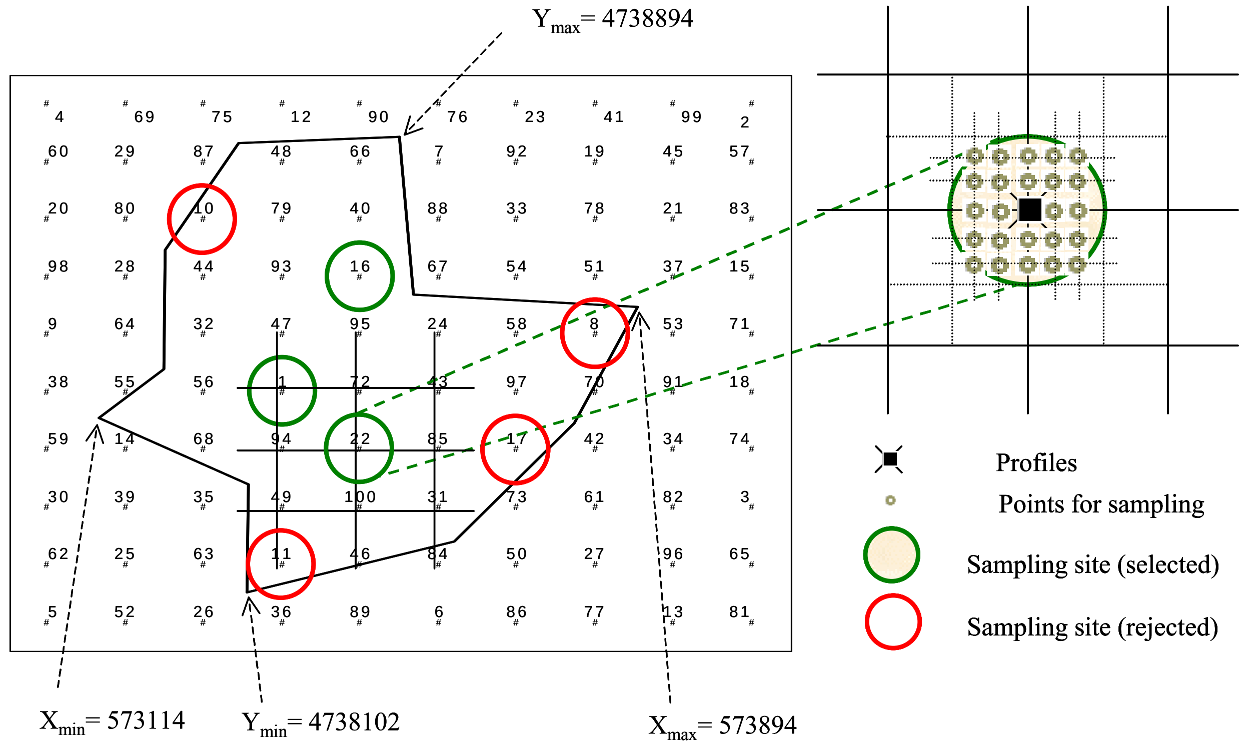

Figure 2. Spatial scheme for soil sampling in the LULUCF plot

For effective implementation of the randomised sampling template illustrated above, the user has to:

- Represent the plot in the standard local projection used for topographic or cadastral maps.
- Select a square in these co-ordinates that contains the plot. The co-ordinates of the corners of this square frame should be preferably "round" figures, Table 1 gives an example of the maximum/minimum co-ordinates of the plot to be sampled and the square frame to be used for sampling.
- Overlay on the square the template with 100 points numbered from 1 to 100, as represented in figure 2.
- Determine the number 'n' of sampling sites that is conditioned by the plot area (Table 2) and the need to keep the costs to a minimum.
- Select the first 'n' points of the grid if they fall inside the plot. Otherwise select subsequent sampling point (n + 1, n + 2, etc.) until you have 'n' points inside the plot.

Coordinate axis	Plot	Square frame
xmin	573114	573000
xmax	573894	574000
ymin	4738102	4738000
ymax	4738894	4739000

Table 1. Model representing the coordinates of the sampling points

In the plot represented in the Figure 2, point '1' of the grid is inside the plot and is therefore selected to the first sampling site. Points 2 to 7 and 9, 12 to 15 are outside the plot and therefore excluded. Subsequently, sampling point 16 is selected. Then, as in the case of sampling point 8, 10,11 and 17 if the selected sampling points does not have the provisional area for comfortable composite samplings as per the norms prescribed above i.e. when it falls around the transition area at the edge of the field demarcation, then these sampling points can be left out as illustrated with red circle in the illustration above (Figure 2).

Size of the plot	Number of composite samples
< 5 ha	3
5 - 10 ha	4
10-25 ha	5
> 25 ha	6

Table 2. Recommended number of composite samples depending on the plot area

To set up sampling template for the LULUCF plot the user has to apply the maximum and minimum x and y co-ordinates of the plot in meters. The maximum will be rounded upwards and the minimum downwards. Then subdivide the difference (e.g., xmax - xmin and ymax – ymin) by 10 and specify sampling grid of 100 ranked points (Figure 1). Details on the European Reference Coordinate System can be viewed and downloaded from http://eusoils.jrc.it/Data.html.

3.2 Soil sampling

A record of the sampled sites and points should be kept, so that they will not be duplicated at a later date. In order to reduce temporal variations, sampling should be confined to periods with low biological activity, e.g. winter or dry season. The resampling has to be carried out in the same period (season) as for the first occasion for all sites. The sampling dates should be reported.

For the determination of bulk density a minimum volume of 100 cm^3 should be taken from non-stony soils. For every LULUCF plot all composite samples have to be taken and analyzed in laboratory. The samples of soil should be of equal weight, except for situations of variable lower depth limit. In such a case (e.g. an indurated horizon within the depth range of the sampled layer), the weight of each sub sample is function of the thickness of the actually sampled layer. The minimum weight of each representative sample should be 500 g to provide sufficient material to perform all necessary analysis and for future storage.

3.2.1 Cropland

The cropland-based soil profile can be schematized by two principal horizons: topsoil (the plough layer) and the subsoil underlying it (Figure 3a).[1]

The plough horizon or layer indicates regular anthropogenic perturbation and physical mixing of soil material throughout, e.g. organic and mineral fertilizers, application of earth, etc. The plough horizon hosts the largest proportion of root biomass and incorporates surface crop residues that

[1] If no-till and non-plough crops are adopted the soil profile turns to have gradual changes of soil characteristics with depth. For this case soil sampling should follows that of pasture.

contribute to the change in organic content in soils. The plough horizon is seldom stratified due to regular tillage. The thickness of the plough horizon is different depending on conventional cultivation in the countries. Therefore, it is proposed that one sample be taken from the middle of the plough horizon, e.g., at 10-20 cm depth if plough horizon is 30 cm thick as illustrated in Figure 3a. An undisturbed soil sample to determine the bulk density should also be taken at the same depth.

3.2.2 Pasture

Pasture soils are exposed to anthropogenic disturbances limited to a reduction in organic input because of biomass consumption through grazing, fertilization, additional grass seeding, etc. The profile of these soils has gradual change of soil characteristics with depth in line with that of natural soils. The good practice guidance (IPCC, 2003) suggests detecting changes of organic carbon stock in 30 cm topsoil. The principal structure and a scheme of soil sampling of pasture are illustrated in Figure 3b.

Column sampling the profile at 10 cm intervals is recommended. These samples will be combined into one composite sample for the laboratory analysis. 'Disturbed' samples, taken at the three similar sampling depths, should be combined too into a composite sample. Sampling to determine bulk density and for laboratory analysis is the same as for cropland soils.

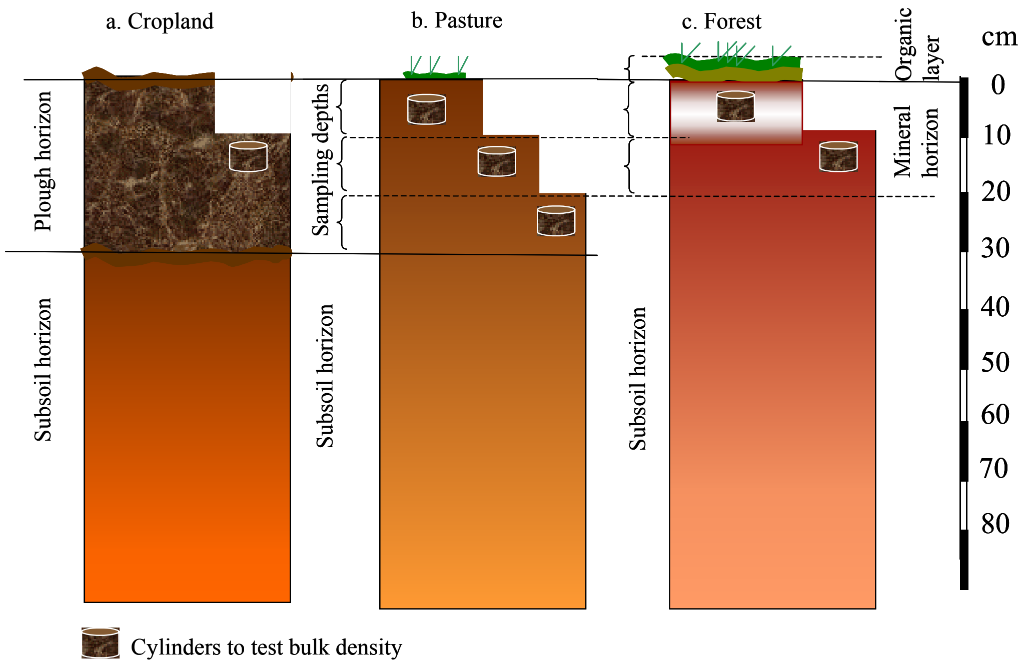

Figure 3. Principal structure and the scheme of soil profile sampling

3.2.3 Forests

General rules for soil sampling in forests of Europe are specified by the ICP Manual (UNECE, 2003) and can be partly adapted, e.g., sampling points should be 1 m distant from tree stems and should avoid animal holes, disturbances like wind-thrown trees and trails. However, ICP Manual centers on monitoring of changes in the point and includes details of litter horizon, which are unnecessary when total organic carbon stock is considered.

As illustrated by the principal structure of soil sampling in forests (Figure 3c) the organic (litter) topsoil is sampled in a whole and accompanied by indication of total thickness of the layer. A frame of 25 by 25 cm is recommended for collecting forest organic layer. In the field, the total fresh weight of forest organic layer should be determined. A sub-sample is collected for the determination of moisture content (weight %) in the laboratory to calculate total dry weight (kg/m^2).

Mineral layers should be sampled at exactly the same locations, i.e. sample the mineral soil underneath the organic layer that has already been removed for sampling. Sampling should be done at fixed depths. The top of the mineral soil corresponds with the zero level for depth measurements. The entire thickness of the predetermined depth should be sampled and not the central part of the layer only. Auguring is preferred and pits are allowed, especially in case of stony soils where augerings are usually difficult and sometimes impossible.

For the determination of bulk density each mineral layer (0-10 and 10-20 cm) of non-stony soils should be taken from.

4 Algorithms

According to Good Practice Guidance the carbon stock account should be measurable, transparent and verifiable (IPCC, 2003). Consequently, the changes in organic carbon stock in soils undergoing LULUCF activity can be certified if based on physically measured carbon stocks prior to (baseline occasion) and after the activity has been undertaken (second occasion), e.g. the latter can be first or second commitment periods, etc. Changes derived from models are complimentary and valuable to define potential for carbon sequestration in the soil of the LULUCF plot at the planning stage of the LULUCF project.

Area frame sampling ensures a reproducibility of the sampling sites. The target is the estimate of the changes in organic carbon stock and its standard error rather than the estimate of organic carbon stock in soils.

4.1 Computation

The computation stems from a few parameters that have to be measured in the field, determined in laboratory and taken from other sources, e.g., cadastral information on LULUCF plot location and area. The list of necessarily parameters includes: the carbon content in soil, the soil bulk density, the thickness of the soil layer, the content of coarse fragments and the area of the LULUCF plot. The computation routine follows steps below:

Step 1: Calculation of soil organic carbon density SCD_{site}[2] for the sampling site:

$$SCD_{site} = \sum_{layer=1}^{j} (SOC_{content} * BulkDensity * Depth * (1 - frag)) \quad (1)$$

Where:

$SOC_{content}$ is a soil organic carbon content, % of mass or $\left(\frac{gC}{kg}\right)$

$BulkDensity$ is a soil bulk density, $\left(\frac{g}{cm^3}\right)$

$Depth$ is a thickness of the sampled layer, cm

$frag$ is volume of coarse fragments, % of mass or $\left(\frac{dm^3}{m^3}\right)$

The SCD_{site} provides an average value for the sampling site, which is derived from taking a composite sample combining a number of sub-samples. According to ISO 10381-4 at least 25 sub-samples should be obtained (see Figure 2).

Step 2: Calculation of mean (arithmetic average) soil carbon density ($\overline{SCD}_p$) for LULUCF plot:

$$\overline{SCD}_p = \frac{1}{n} \sum_{site=1}^{n} SCD_{site} \quad (2)$$

Where:

SCD_{site} is as indicated in Equation 1

n is a number of sampled sites within the plot

Step 3: Calculation of reference soil organic carbon stock ($SOC_{refstock}$) for the LULUCF plot:

$$SOC_{reference} = \overline{SCD}_p * A_p \quad (3)$$

---

[2] SCD refers to carbon concentration $\left(\frac{kgC}{m^2}\right)$ or $\left(\frac{tC}{ha}\right)$ related to a layer of soil, e.g., 0-0.3, 0-05, 0-1.0, 0-2.0 m. The SCD should not be confused with carbon content in soils, which is fraction of carbon by weight of soil expressed in per cent or $\left(\frac{gC}{kg}\right)$.

Where:

$S\overline{C}D_p$ as indicated in Equation 2

A_p is an area of the LULUCF plot

Step 4: Calculation of changes (ΔSOC_{stock}) in organic carbon stock in soils[3]:

$$\Delta SOC_{stock} = SOC_{new} - SOC_{refstock} - f_{org} - f_{\lim} \qquad (4)$$

Where:

$SOC_{refstock}$ is as indicated in Equation 3

SOC_{new} is a new soil organic carbon stock (second occasion) after LULUCF implementation compute similar to $SOC_{reference}$

f_{org} is C applied with organic fertilizers

f_{lim} is C applied with lime

4.2 Uncertainty

The IPCC good practice guidance (IPCC, 2003) defines uncertainty as a parameter, associated with the result of measurement that characterizes the dispersion of the values that could be reasonably attributed to the measured quantity. The uncertainty of the changes in organic carbon stock for the LULUCF plot can be characterized by standard error of the changes value that can be computed by the steps below:

Step 5: Calculation of standard error for mean soil carbon density $s(\Delta S\overline{C}D_p)$:

$$s(\Delta S\overline{C}D_p) = \sqrt{\frac{1}{n(n-1)} \sum_{site=1}^{n} \left(\Delta SCD_{site} - \Delta S\overline{C}D_p\right)^2} \qquad (5)$$

Where:

$\Delta SCD_{site} = SCD_{new} - SCD_{reference}$

$\Delta S\overline{C}D_p$ is the average of ΔSCD_{site} for the sites sampled in the plot

n is a number of sampling sites within LULUCF plot

Step 6: Calculation of standard error of the changes of organic carbon stock $s(\Delta SOC_{stock})$ in the LULUCF plot:

[3] This equation describes the changes of organic carbon stock due to sequestration from the atmosphere.

$$s(\Delta SOC_{stock}) = s(\Delta S\overline{C}D_p) * A_p \quad (6)$$

Step 7: The overall result in weight of SOC and its standard error is:

$$\Delta SOC_{stock} \pm s(\Delta SOC_{stock})$$

Expressing the result inaccuracy in terms of standard error allows to avoid the normality assumptions.

5 Terms and definitions

Accuracy: a relative measure of the exactness of an emission or removal estimate.

Certification: is a process which is in a written quality statement (a certificate) attesting the amount of organic carbon stock in soils and its changes due to LULUCF activities.

Coarse fragments: stones (with a diameter > 2cm) and gravel (with a diameter > 2mm).

Cropland: arable and tillage land, and agro-forestry systems where vegetation falls below the threshold used for the forest land category, consistent with the selection of national definitions.

Forest land[4]*: woody vegetation consistent with thresholds used to define forest land in the national GHG inventory, subdivided at the national level into managed and unmanaged and also by ecosystem type as specified in the IPCC Guidance. It also includes systems with vegetation that currently falls below, but is expected to exceed, the threshold of the forest land category.*

LULUCF plot: a piece of land comprising LULUCF land category (e.g., cropland, pasture, forest), which is undergoing activities to enhance carbon removals by carbon sink in soil.

Mineral soil material: a material having less organic carbon or organic matter content than that of the organic material.

Organic soil material (WRB, 1998, p.56-7): consists of organic debris which accumulates at the surface under either wet or dry conditions and in which any mineral component present does not significantly affect the soil properties.

1. if saturated with water for long periods (unless artificially drained), and excluding live roots, either:

- 18 percent organic carbon (30 percent organic matter) or more if the mineral fraction comprise 60 percent or more clay; or

[4] *Forest*: is a minimum area of land of 0.05-1.0 hectares with tree crown cover (or equivalent stocking level) of more than 10-30 per cent with trees with the potential to reach a minimum height of 2-5 meters at maturity *in situ*. A forest may consist either of closed forest canopy where trees of various stories and undergrowth cover a high portion of the growth or open forest. Young natural stands, and all plantations which have yet to reach a crown density of 10-30 per cent or tree height of 2-5 meters, are included under forest, as are areas normally forming part of the forest area, which are temporarily unstocked as a result of human intervention such as harvesting or natural causes but which are expected to revert to forest.

- 12 percent organic carbon (20 percent organic matter) or more if the mineral fraction has no clay; or
- a proportional lower limit of organic carbon content between 12 and 18 percent if the clay content of the mineral fraction is between 0 and 60 percent; or

2. if never saturated with water for more than a few days, 20 percent or more organic carbon.

Quality control: a system of routine technical activities, to measure and control the quality of the inventory as it is being developed.

Pasture: grassland managed for grazing.

Points for sampling: a location at which a sample of soil is taken to be combined in the composite sample.

Sample: a fragment of soil selected from the soils of LULUCF plot.

Sampling site: a location within LULUCF plots at which physical soil sampling takes place.

Soil profile: a location within LULUCF plots at which soil pit is established and undisturbed samples and soil descriptions are made.

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[5] The Map of "Topsoil Organic Carbon Content" is used for the cover page (http://eusoils.jrc.it/themes.html)

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