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

Version 2

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Cover Photograph: Aerial photograph of plot in Calabria, bounded by yellow line, overlain with the sampling template in red with the profile positions and cell numbers. Inset shows soil sampling in Marche Region.

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1. Introduction

The study of the soil has always represented a challenge for the scientific community. Soil forms a continuum in space, so that classification is often difficult. Soil has a vertical dimension (depth), but many characteristics are not being visible from the surface. Its properties vary very slowly over time, so that changes are difficult to detect. The study of soil heavily depends on the sampling strategy, including the location of the observation sites, the timing of investigation, the depth of a pit (known as a soil profile), the techniques and tools of samples collection, etc. Soil characteristics derived from various sampling procedures can differ significantly. This specific nature of soil makes the establishment of the sampling methodology a fundamental element of any soil research. Given this priority, the International Organization for Standardization (ISO) has established a standard (ISO, 2002) that describes the principle rules for designing soil-sampling strategies and techniques for collecting samples. In this document, the ISO emphasizes that sampling strategy is driven by the purpose of the research and therefore the general rules must be adapted to the concrete goals.

Soil Organic Carbon (SOC) is a measure of the total amount of organic carbon (C) in soil, independently of its origin or decomposition. Interest in SOC is common among soil scientists and related practitioners because of the importance for principle physical, chemical and biological soil ecological functions and because SOC is a universal indicator of soil quality. Consequently, as variations in SOC levels can have serious implications on many environmental processes such as soil fertility, erosion and greenhouse gas fluxes, the need to estimate SOC changes has become central to several pan-European and global environmental policies.

At a European level, SOC is considered in many policies and strategies of the European Union (EU). The Sixth Environment Action Programme[1] required the European Commission to prepare a Thematic Strategies on Soil Protection. The resulting Communication (COM(2006) 231[1], adopted by the European Commission on 22/09/2006) sets out the overall objectives through a proposal for a Framework Directive (COM(2006) 232[1]) that establishes common principles for protecting soil functions against a range of threats. One of the key goals of the Strategy is to maintain and improve SOC levels. The Directive is supported by an Impact Assessment (SEC

[1] documents are available at http://ec.europa.eu/environment/soil/index.htm

(2006) 1165[1] and SEC(2006) 620[1]) that contains an analysis of the economic, social and environmental consequences of the different options for soil protection. The assessment reveals that the cost of not taking any additional action to improve the management of SOC stocks (i.e. maintaining the *status quo*) were significantly higher than the costs of measures to protect soil.

At the international level, all the various Conventions arising from the 1992 United Nations Conference on Environment and Development in Rio (e.g. Climate Change, Biodiversity and to Combat Desertification) have the issue of SOC levels at their core. The Kyoto Protocol (UNFCCC, 1998), in particular, allows the use of biospheric carbon sinks and sources originating from human-induced activities to meet the Countries' commitments of greenhouse gas emissions reduction. These activities, listed in Article 3.3 (afforestation, reforestation and deforestation since 1990) and Article 3.4 (forest management, cropland management, grazing land management, re-vegetation) of the Kyoto Protocol, are collectively named "Land Use, Land-Use Change and Forestry" (LULUCF) activities[2]. The soil is among the mandatory carbon pools to be reported for these activities under the Kyoto Protocol[3] and it is certainly one with the highest potential, both in terms of enhancement of C sink and reduced C emission[4]. The procedures for estimating changes in SOC under the Kyoto Protocol are described by the International Panel on Climate Change report 'Good Practice Guidance for LULUCF' (IPCC, 2003). However, as this document mainly addresses general principles – with a focus on the approaches to be applied at the Country scale depending on the level of methodological complexity ("Tier") -, a more specific protocol for estimating SOC changes even at the plot level (e.g., agricultural field, pasture or forest stand) would be very useful.

Hence, there is an urgent need to develop a common, simple, transparent and cost effective method to identify the changes of SOC in mineral soils of the EU. In order to meet this challenge, a new method referred to as the "Area-Frame Randomized Soil Sampling" (AFRSS) has been developed by the European Commission's Directorate General Joint Research Centre (JRC) in Italy (Stolbovoy et al., 2005a). Although this

[2] While the reporting and accounting of Art. 3.3 activities is mandatory, each of the Art. 3.4 activity is eligible for accounting or not.

[3] Reporting SOC changes is mandatory except if "transparent and verifiable information is provided that this pool is not a source"

[4] For a more detailed discussion on the agricultural and forestry activities having potential for C sink or for emissions reduction, see results of the European Climate Change Programme (ECCP) - Topic Group Agriculture and Forestry (http://ec.europa.eu/environment/climat/pdf/eccp/review_agriculture.pdf)

methodology mainly addresses the need of a cost-effective estimation of SOC change arising from specific projects or regional/national policies aimed at increasing soil carbon, potentially it may be used also to support country-level reporting under the Kyoto Protocol, through the improvement of specific components of the IPCC's default methodologies (e.g., by estimating detailed stock change factors).

The first version of the AFRSS method was developed from mainly theoretical considerations, lacked field validation and was insufficient to define boundary conditions without which a practical application of the AFRSS method for field survey is difficult. To overcome this deficiency, a number of studies have been carried out to validate the method (Stolbovoy et. al., 2005b; Stolbovoy et al., 2006). The AFRSS method was tested by regional soil survey organizations throughout Italy in a wide range of natural conditions (see http://eusoils.jrc.ec.europa.eu/). The current updated revision of the manual incorporates practical experiences derived from the field and includes numerous comments from users. In addition, the revised manual is illustrated by worked examples.

The objective of this report is to introduce a second, updated, version of the Protocol for soil sampling (Stolbovoy et al., 2005) which includes improved text on:

- Technical specification;
- Location of the sampling sites;
- Sampling quantity and composition;
- Sample collection;
- Data acquisition and accuracy control;
- Field validation of the AFRSS method.

2. Standard norms

The Protocol follows the general requirements of the International Standard (ISO/FDIS 10381-1:2002(E)) (ISO, 2002a) and is particularly relevant to ISO 10381-4 (ISO, 2002b) which is devoted to "Sampling to support legal or regulatory action", covering the requirements to establish baseline conditions prior to an activity which might affect the composition or quality of soil.

Sampling strategies included in the Protocol are consistent with the general principles of the IPCC Good Practice 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).

Data collection and laboratory analysis are based on Italian guidelines and standards (e.g. *Ministero per le Politiche Agricole,* 1997; *Ministero per le Politiche Agricole*, 2000; IPLA, 2006).

3. Technical specification

3.1 Template description

At the core for the AFRSS method is a randomized sampling template that represents a grid of 100 cells that enables a ‘modified’ random sample collection with a distance threshold to be carried out. The numeration of the sampling cells is selected at random with particular care being placed to prevent a previously sampled cell being too close to subsequent ones, which can occur for pure random sampling plans. Sampling plans that avoid points too close to each other, give a lower variance than simple random sampling (Bellhouse, 1977); this happens in particular for systematic sampling (Bellhouse, 1988). The sampling scheme used in this approach behaves approximately like a systematic sampling plan in the sense that points too close to each other are avoided and is more flexible than systematic plans to adjust a small sample size in areas with an irregular shape.

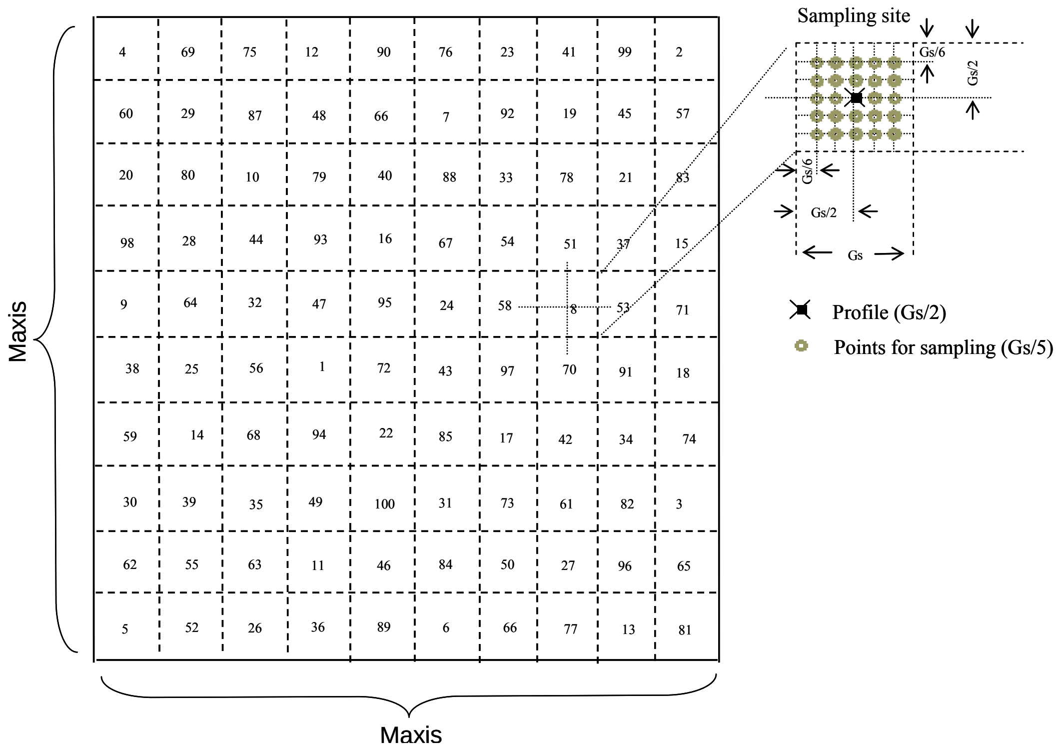

Figure 1. Area-frame randomized template and its parameterization (for explanation see text).

The spatial parameters of the template are flexible and adjusted to the size and geographical coordinates of the sampling plot (e.g. a field/pasture/forest). To define the dimension of the template, the longest X or Y axis (Maxis) of the plot should be found (Figure 1). The grid size (Gs) is calculated by dividing Maxis by 10. This grid is matched with the plot and is applied to position the sampling sites. The amount of the latter is defined by the plot area (Table 1). Each sampling site comprises a number of sampling points for collecting the composite soil samples and soil profile. Following ISO recommendations (ISO, 200a), the number of sampling points for the composite soil sample should be 25[(5)]. To define the distances between sampling points, Gs is divided into a 5 x 5 grid, which is Gs/6. The central sampling point within the grid is assumed to be the position of the soil profile and is found by dividing Gs by 2. Soil description, collection of undisturbed cylinder samples for bulk density[6], litter and coarse debris[7] should be taken in this point.

[5] There is a proposal from the field surveyors in Italy that the number of the sampling points for the composite soil sample can be reduced to nine. However, this suggestion currently lacks experimental data and cannot be taken at present.

[6] The undisturbed cylinder samples are not accurate enough for bulk density measurements and cannot be taken easily in the dry season. Most surveyors prefer using local pedo-functions which provide more

3.2 Adaptation of the template[8]

For effective implementation of the randomised sampling template (Figure 1), the user has to:

- Represent the plot (field/pasture/forest) margins in X and Y coordinates of the standard local projection used for topographic or cadastral maps.
- Define the X and Y extents of the plot and take the longest axis (Maxis). Setup a square frame having Maxis size and match it with the plot. The coordinates of the corners of this square frame should be preferably integer values.
- Overlay the template with 100 grids numbered from 1 to 100, as represented in Figure 1.
- Determine the number (n) of sampling sites (grids) that is conditioned by the plot area and the need to minimise costs (Table 1).
- Select the first sampling site (grid) having the lowest number within the plot. If the next site (grid) falls outside the plot, the next sampling site (grid) must be selected until ‘n’ sites (grids) will be identified.

Table 1. Recommended number of sampling sites (grids of the template) depending on the plot area.

Size of the plot	Number of sampling sites (n)
< 5 ha	3
5 - 10 ha	4
10-25 ha	5
> 25 ha	6

3.3 Sampling location

Following the adaptation procedure, the geographical position of the plot (field/pasture/forest), together with the location of the sampling sites and soil profiles are presented in the local coordinate system. To keep a consistent register of each

reliable data. We suggest relying on the experience of the local specialists to select either direct field cylinder sampling or make use of available pedo-functions to define soil bulk density.

[7] High stone content might be a constraint for the widespread application of the AFRSS method in the stony soil. This is especially relevant for mountainous regions with fragmented soil cover and abundant rock outcrops.

[8] To apply the present procedure, a specific ESRI ArcGis script is available at http://arcscripts.esri.com/details.asp?dbid=14781

sampled field, pasture or forest plot at EU level, the geographical positions should be fixed in the European Coordinate Reference Systems (CRS identifier ERTS89, Ellipsoidal CRS) (Boucher and Altamini, 1992). The position should be recorded as precise as possible by means of Global Positioning Systems (GPS) to enable 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.

3.4 Pedological details

A record of the sampled sites and points should be kept. In order to reduce temporal variations, sampling should be confined to periods with low biological activity, such as the winter or during the dry season. Any resampling should be carried out in the same period (season) as for the initial sample for all sites. The sampling dates should be reported.

For the determination of bulk density, an undisturbed sample with a minimum volume of 100 cm^3 cylinder should be taken from non-stony soil. For every sampling site, composite samples should be taken and analyzed in the laboratory. The composite soil samples from the sampling sites should be of equal weight, except for situations where the subsoil is shallow. In such cases (e.g. an indurate horizon within the depth range of the sampled layer), the weight of each sub sample is function of the thickness of the sampled layer. The minimum weight of each composite sample should be at least 500 g to provide sufficient material to perform all necessary analysis and for future storage.

3.4.1. Cropland

A soil profile under cropland can be schematized by two principal horizons: topsoil (the plough layer) and the underlying subsoil (Figure 3a).[9]

The plough horizon or layer indicates regular anthropogenic disturbance and physical mixing of soil material (e.g. application of organic and mineral fertilizers, addition of soil improvers, etc.). The plough horizon hosts the largest proportion of root biomass and incorporates surface crop residues that contribute to the change in SOC content.

[9] If no-till or no-plough land management practices are adopted, the soil profile will exhibit a gradual change of soil characteristics with depth. In this case, the soil sampling scheme should follow that of pasture land.

The plough horizon is seldom stratified due to regular tillage. As the thickness of the plough horizon differs according on cultivation practices, then the AFRSS methodology proposes to keep the sampling depth in accordance to the existent thickness of the plough layer. One sample should 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 with the cylinder to determine the bulk density should be taken at the same depth.

3.4.2. Pasture

Soil under pasture is exposed to limited anthropogenic disturbances and a reduction in organic inputs because of biomass consumption through grazing. The soil profile under such land use displays a gradual change of soil characteristics with depth. For these soil types the IPCC Good Practice Guidance (IPCC, 2003) suggests detecting changes of SOC stock in the upper 30 cm topsoil. This sampling strategy is illustrated by Figure 3b.

The AFRSS methodology follows the IPCC rules and proposes a column soil sampling procedure at 10 cm intervals. However, to reduce costs, the column soil samples should be combined into a single composite sample for laboratory analysis. In a similar manner to the undisturbed cylinder samples for bulk density, the 'disturbed' samples, taken at three comparable sampling depths, should be combined into a composite sample.

3.4.3. Forests

General rules for soil sampling in the forests of Europe are specified by the ICP Manual (UNECE, 2003) and can be partly adapted, for measurements of SOC (e.g., sampling points should be 1 m distant from tree stems and should avoid animal holes and disturbances such as wind-thrown trees and trails). However, the ICP Manual centers on details (e.g. litter fractions) that are unnecessary for detection changes in total SOC stock.

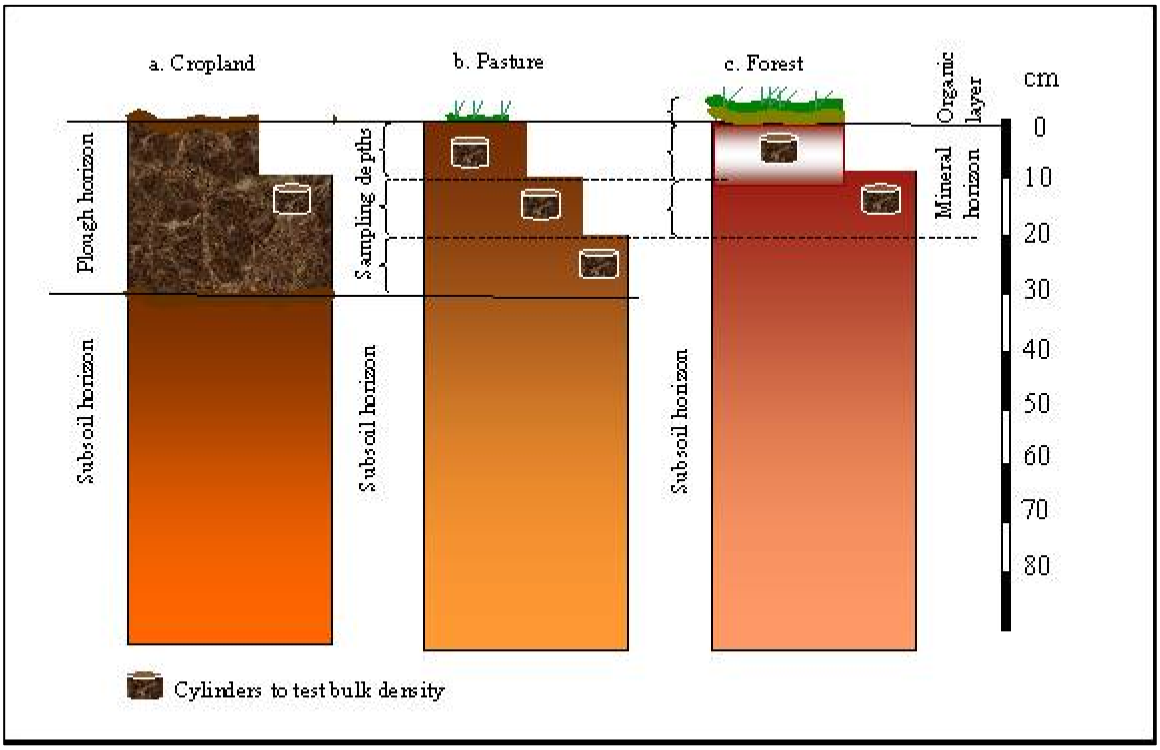

Figure 3. Principal structure and the scheme of soil profile sampling

As illustrated by Figure 3c, when sampling soil in the forest, the organic (litter) topsoil is sampled as a whole and accompanied by an indication of the total thickness of the layer. A frame of 25 cm by 25 cm is recommended for collecting forest litter. In the field, the total fresh weight of the forest litter 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. underneath the litter that has already been removed for sampling). Sampling should be done at fixed depths. The top of the mineral soil corresponds to the zero level for depth measurements. The entire thickness of the predetermined depth should be sampled and not only the central part of the layer. Auguring is preferred and pits are allowed, especially in case of stony soil where auguring is usually difficult and sometimes impossible.

To determine the bulk density of each mineral layer (0-10 and 10-20 cm) of non-stony mass a cylinder of undisturbed samples should be taken.

4. Algorithms

According to the Good Practice Guidance (IPCC, 2003), the SOC account should be measurable, transparent and verifiable. The AFRSS method follows this recommendation. Estimates of SOC changes derived from models are complimentary and valuable for defining the potential for carbon change in the soil.

It is important to emphasize that the goal of the AFRSS is the verification of the changes in SOC stock and its standard error. The SOC change is a relative term for which an absolute SOC value is insignificant. This makes the procedure of By applying spatial grids for the sampling, the method ensures a reproducibility and accuracy of the measurements for the geographically fixed sampling sites.

4.1. Computation

The computation of SOC stock is based on a few parameters that must be measured in the field, determined in laboratory or taken from other sources (e.g. cadastral information on the plot location and area). The list of parameters includes: the carbon content in soil, bulk density, the thickness of the soil layer, the content of coarse fragments and the area of the plot. The computation routine follows the steps outlined below:

4.1.1. Step 1: Soil organic carbon density (SCD) for sampling site

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

Where:

$SOC_{content}$ is a SOC content, % of mass $\left(\frac{kgC}{kgSoil} X100 \right)$;

$BulkDensity$ is a soil bulk density, $\left(\frac{kgSoil}{dm^3} \right)$;

$Depth$ is a thickness of the sampled layer, dm;

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

The SCD_{site} provides an average value for the sampling site, which is derived from a composite sample (Figure 2).

4.1.2. Step 2: Mean (arithmetic average) soil carbon density ($S\overline{C}D$) for plot

$$S\overline{C}D_p = \frac{1}{n}\sum_{site=1}^{n} SCD_{site} \tag{2}$$

Where:

SCD_{site} is as indicated in Equation 1;

n is a number of sampled sites within the plot.

4.1.3. Step 3: Reference soil organic carbon ($SOC_{reference}$) stock for plot

$$SOC_{reference} = S\overline{C}D_p * A_p \tag{3}$$

Where:

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

A_p is an area of the plot.

4.1.4. Step 4: Changes in organic carbon stock[10] (ΔSOC_{stock}) for plot

$$\Delta SOC_{stock} = SOC_{new} - SOC_{refstock} - f_{org} - f_{\lim} \tag{4}$$

Where:

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

SOC_{new} is a new (determined during subsequent field campaign) SOC stock;

f_{org} is C with organic fertilizers (if applied);

f_{lim} is C with lime (if applied).

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 SOC stock for the plot can be characterized by the standard error of the changes as computed by the following steps:

[10] This equation describes the changes of SOC due to sequestration from the atmosphere.

4.2.1. Step 5: Standard error of mean soil carbon density ($s(\Delta S\overline{C}D_p)$) for plot

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

Where:

$\Delta SOC_{site} = SCD_{new} - SCD_{reference}$ is a change in SOC stock for the sampling site;

$\Delta S\overline{O}C_p$ is the average of ΔSOC_{site} for the plot;

n is the number of sampling sites within the plot.

4.2.2. Step 6: Standard error of organic carbon stock ($s(\Delta SOC_{stock})$) for plot

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

Where:

$s(\Delta S\overline{C}D_p)$ is as indicated in Equation 5;

A_p is the area of the plot.

4.2.3. Step 7: Result

$$\Delta SOC_{stock} \pm s(\Delta SOC_{stock}), \text{ where} \tag{7}$$

ΔSOC_{stock} is the weight of the SOC stock change and $s(\Delta SOC_{stock})$ is the standard error of the latter. Expressing the inaccuracy of the result in terms of standard error does not require normality assumptions but does not give a specific level of confidence.

4.3 Reproducibility of the sampling result

The AFRSS method can be fully implemented if time series observations are available (at least two on the same sites). Clearly, calculation of the changes (ΔSOC_{stock}) in SOC stock (Step 4) and the detection of the uncertainty (Steps 5-6) are impossible for a single time observation.

However, for single time observation, the reproducibility (RP) of the AFRSS method can be assessed. The RP refers to the relative difference in the averages $S\overline{O}C$ stock resulting from two parallel samplings (e.g. if two GPS devices are used to establish position of sampling sites). Substantially, this parallel sampling simulates an error of the average $S\overline{O}C$ stock coming from the uncertainty of positioning the sampling site. This error originates from the inherent variability of soil characteristics over short distances, which are not tackled by the ARFSS sampling.

Technically, the RP can be defined as follows: 1) the sampling at the initial sampling campaign is described above; 2) at the second sampling campaign, the sampling sites can be reposition by applying another GPS device. The difference in sites positioning will be within few meters depending on the GPS quality, satellite location, etc. If the second GPS device is unavailable the repositioning of the sampling sites can be done arbitrarily. The procedure of the second time sampling is similar to that of the first one. Additional computational steps to define the RP will be:

4.3.1. Step 8: Difference (absolute) in averages of soil organic carbon stock (ΔSOC_{plot}) between first (reference) and second samplings for a plot

$$\Delta SOC_{plot} = \left| S\overline{O}C_{stock1} - S\overline{O}C_{stock2} \right| \tag{8}$$

where

$S\overline{O}C_{stock1}$ and $S\overline{O}C_{stock2}$ are average SOC stocks for the first and second sampling campaigns within a given plot.

4.3.2. Step 9: Reproducibility (RP_{plot}) of sampling result for plot

$$RP_{plot} = \frac{\Delta SOC_{plot}}{S\overline{O}C_{stock1}} \times 100 \tag{9}$$

where

RP_{plot} is given in percent.

5. Validation

To bring any new method into practice requires considerable validation efforts. It is essential to adopt the method into a practical tool for field surveyors, set up boundary conditions and evaluate the economic cost. In order to validate the AFRSS methodology, a number of test sites were selected in different soil conditions across the EU (see http://eusoils.jrc.ec.europa.eu). This document presents the results of the validation exercise carried out in the Piemonte Region of Northern Italy (Stolbovoy et al., 2006).

The main objective of this section is to demonstrate the applicability of the AFRSS method including:

- Step by step practical implementation;
- Computation examples;
- Cost estimate;
- Observation of the results.

5.1. Estimate of the reference soil organic carbon stock (SOC_{stock})

5.1.1 Cropland

The cropland test site is situated between the towns of Caselle and Leinì on the alluvial plain of the Stura River, close to Turin airport, an area which was characterised in the recent past by irrigated grasslands for cattle feeding. The expansion of intensive maize cultivation has brought about a conversion of this area to arable land but with the associated environmental consequences of higher risks of contamination of groundwater in a very permeable substratum by agro-chemicals.

The soil of the cropland plot is common for most flat alluvial cones, formed by gravely and sandy deposits with a deep groundwater table which does not affect the soil hydrological regime. The parent material is rich in greenstones and lacks carbonates. The land use is mainly agricultural with prevalence for rotated cultivations and grasslands. The particular plot has been under crop rotation (maize, corn, grass) since 20-30 years.

The soil is characterised by a loamy or silty-loam texture and by low macro porosity due to iron oxides (mottling and concretions). Root development is restricted by the presence of gravely layers at 45-50 cm depth. Due to the coarse texture and abundance of gravels, the aeration of soil and oxygen availability for plants is good. The internal drainage of soil profile and saturated hydraulic conductivity are moderately high. A typical soil profile will exhibit a brown topsoil, sandy-loam, 15% gravel, acid or subacid pH; underlain by a yellowish brown subsoil with some reddish shade, sandy-loam with gravel over 35%, subacid pH. Gravels and sands constitute the substratum. The Ca/Mg ratio is lower due to the presence of greenstones and limited soil chemical fertility.

Soil Classification:

Soil series: FOGLIZZO coarse-loamy over sandy-skeletal, gravelly.

Soil Taxonomy: *Dystric Eutrudept, coarse-loamy over sandy-skeletal, mixed, nonacid, mesic*

WRB: *Skeletic Cambisol*

5.1.1.1 SAMPLING PARAMETRIZATION FOR CROPLAND

The geographic coordinates of the cropland plot are given in Table 2. The Xmax value is 2175 and Xmin is 1899. By computation (Xmax - Xmin) the difference is 276.0m. Applying the same operation to the Y coordinates, the difference (Ymax – Ymin) is 209.0 m. The longest axis value (Maxis) is 276 m which defines the size of the template square (Figure 1). Based on this Maxis value, the Gs value is 276/10 = 27.6 m. Consequently, the distance between sampling points (Gs/6) is 4.6 m. The poison of the soil profile (Gs/2) is 13.8 m in the grid.

Table 2. Geographical coordinates of the cropland plot (values in bold indicate coordinates of the plot – see Fig 3).

Plot coordinates	X (meters)	Y (meters)
North	**2175,000**	828,000
South	1978,107	**749,007**
West	**1899,000**	852,000
East	2098,094	**958,052**

Based on the cropland plot area, the number 'n' of sampling sites can be defined (Table 1). As the area of cropland plot is less than 5 ha, the number of sampling sites should be 3. Following the procedure described in the methodology section, the 1st, 8th and 22nd grids have been selected (Figure 3).

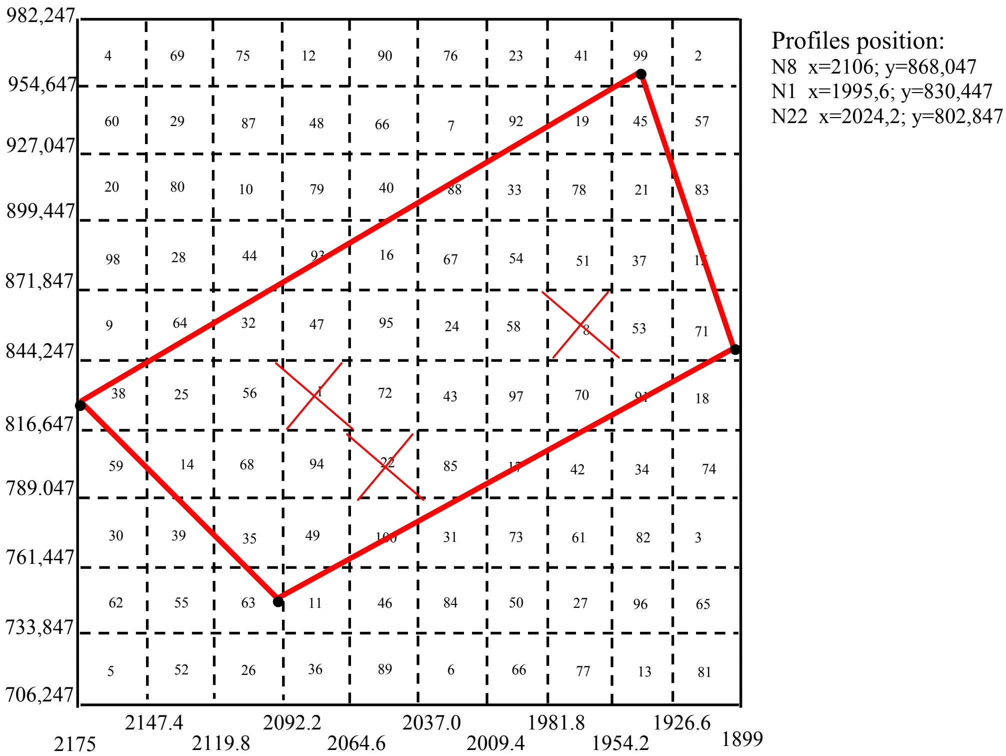

Figure 3. Adaptation of the template to the cropland plot and soil profiles positioning (red crosses).

5.1.2 Pasture

The pasture plot is located in the mountainous region of the 'Valli di Lanzo' in the western-central part of Piedmont (Turin Province), at the head of the Tesso valley.

The plot is representative of glacial relief from the last ice age. Around the glacial *cirque* occupied by Lake Monastero, moraine accumulations and outwash features are found. The soil profile of the pasture plot is characterized by two horizons: the upper horizon is few centimetres deep and rich in organic matter. The lower horizon is transitional to the rocky substratum, which is characterized by mixed lithologies of greenstones and gneiss.

The shallow depth of the profile is due to the slow rate of soil forming processes in the mountain environment and by the relatively young age of the soil. These factors are the principle limitations of the soil. The pedon is characterized by a high anisotropy due to variability of micro-relief which brings different depth and percentage of rock fragments. Consequently, the herbaceous cover and root development are to be considered irregular in depth and quantity.

Soil Classification:

Soil series: not attributed

Soil Taxonomy: Lithic Cryorthent, coarse-loamy, mixed, acid, frigid

WRB: Dystric Leptosol

5.1.2.1 SAMPLING PARAMETRIZATION FOR PASTURE

The geographic coordinates of the pasture plot are given in Table 3. The Xmax value = 376255 and Xmin = 375917. By computation (Xmax - Xmin), the difference is 338 m. Applying the same calculation to the Y coordinates, the difference (Ymax – Ymin) is found to be 343 m and as the longest value corresponds to the Maxis, which defines the dimensions of the template square (Figure 1). Based on the Maxis value, the Gs value is 343/10=34.3 m. Consequently, the distance between sampling points (Gs/6) is 5.7 m. The position of the soil profile (Gs/2) is 17.1 m in the grid.

Table 3. Geographical coordinates of the pasture plot (values in bold indicate coordinates of the plot – see Fig 4).

Axis Coordinate	X (meters)	Y (meters)
North	6026	**669**
South	6162	**326**
West	**5917**	521
East	**6255**	513

The procedure to identify the number (n) of sampling sites was already described in the cropland section. The same operation in this case results in three sampling sites and the respective positioning of the soils profiles are given in Figure 4.

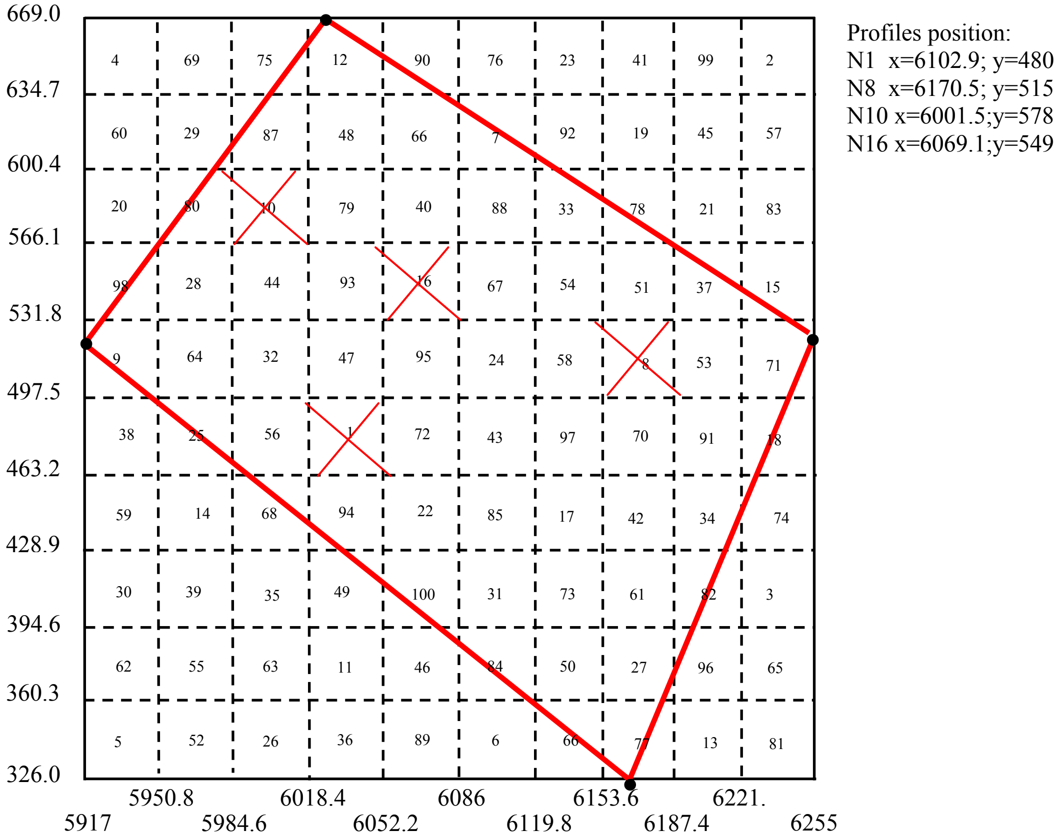

Figure 4. Adaptation of the template to the pasture plot and soil profiles positioning (red crosses).

5.1.3 Forest

The forest plot is situated in the south of the Vercelli Province at 150 m a.s.l., on the lower level of an old river terrace, originally covered by woodland (known locally as the '*Partecipanza of Trino*') before being cleared for rice cultivation. Since the 1990s, the area has been converted to oak plantation. The terrace is a portion of the ancient plain, suspended on the actual Po alluvial area by around 20 m. The site is constituted by colluvial eroded soil from the terrace that has slipped along the slope to the bottom of the relief, formed on gravely deposits rich in fine sands and in clay. The original slopes are only slightly recognizable due to the arrangement of rice-chambers. Surface stoniness is very low.

The soil profile of the forest plot is characterised by a loamy or silty-loam texture with low macro porosity due to iron oxides (mottling and concretions). Drainage and oxygen availability for plants are moderate. Soil variability is sharpened by two factors: irregular distribution of organic matter due to plastic films used in wood arboriculture and irregular patterns of soil texture and bulk densities due to mixing of soil layers in rice-field arrangements for water submersion. The soil profile is represented by loam topsoil with acid pH, often conditioned by sub merged cultivation. The subsoil is constituted by a sequence of eluvial-illuvial layers with loamy texture with evidence of clay coats and neutral pH. The C horizon is well recognised below 160 cm with colours varying from olive-brown to yellowish-brown with mottles and contains much more gravel that subsoil.

Soil Classification:

Soil series: *Ramezzana fine-silty, typic*

Soil Taxonomy: *Aquic Haplustalf, fine-silty, mixed, nonacid, mesic*

WRB: *Gleyic Luvisol*

5.1.3.1 SAMPLING PARAMETRIZATION FOR FOREST

The geographic coordinates of the forest plot are given in Table 4. The Xmax value = 929 and Xmin = 514. By computation (Xmax - Xmin), the difference is 415 m. Applying the same operation to the Y coordinates, the difference (Ymax – Ymin) is found to be 131 m. The longest value (Maxis) is 415 m and is used to define the dimensions of the template square (Figure 1). Based on the Maxis, the Gs value is 415/10 = 41.5 m. The distance between sampling points (Gs/6) is 6.9 m. The poison of the soil profile (Gs/2) is 20.7 m in the grid.

Table 4. Geographical coordinates of the forest plot (values in bold indicate coordinates of the plot – see Fig 5).

Axis Coordinate	x	y
North	**514**	**737**
South	**929**	733
West	917	**606**
East	597	678

By calculation, the number of the sampling sites is 3 and their position and geographical coordinates are given in Figure 5.

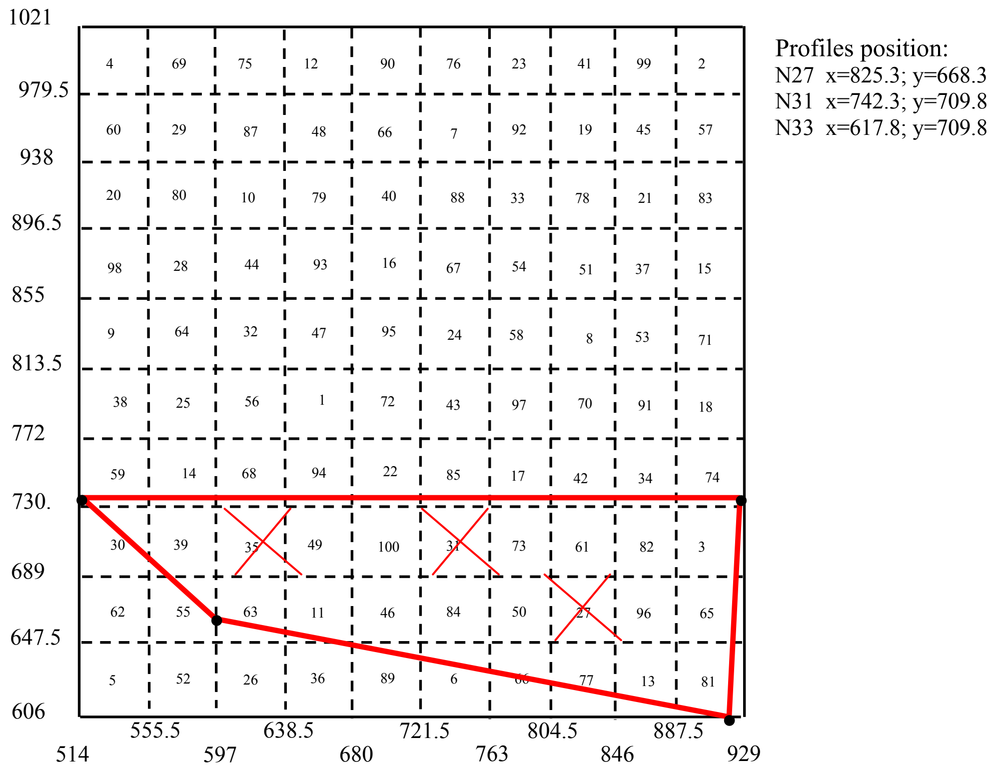

Figure 5. Adaptation of the template to the forest plot and soil profiles positioning (red crosses).

5.2 Computation

5.2.1 Reference soil organic carbon stock (SOC_{stock})

The reference SOC stock is the initial (baseline) amount of the total SOC of the field, pasture or forest plot. The computation follows three steps described in the algorithms section. A summary of the soil characteristics is given in Table 5.

Table 5. Basic soil characteristics and reproducibility of the results of the carbon detection for cropland and pasture in Piemonte region.

Profile, N	Depth, cm	C, %	Bulk density, g/cm3	Soil carbon density, kgC/m3	Carbon content for profile, tC/ha	Soil carbon stock, tC (area 4 ha)	Average soil carbon stock, tC (area 4 ha)	Difference in average carbon stocks between samplings, %
Cropland *Skeletic Cambisol*, first sampling								
C1S	0-25	2.43	1.29	7.86	n.a.*	314.4	301.1	
C22S		2.16	1.43	7.72	n.a.	308.8		
C8S		2.04	1.37	7.00	n.a	280.0		
Cropland *Skeletic Cambisol*, second sampling								3
C1Ss	0-25	1.99	1.52	7.60	n.a.	304.0	292.0	
C22Ss		2.00	1.40	7.00	n.a.	280.0		
C8Ss		1.55	1.25	4.85	n.d.**	n.d.		
Pasture *Dystric Leptosol*, first sampling								
P8S	0-10	7.38	1.07	7.90	181.0	723.8	516.2	
	10-20	8.36	1.22	10.20				
P1OS	0-10	8.00	0.43	3.44	111.1	444.5		
	10-20	5.60	1.37	7.67				
PIS	0-10	6.97	0.77	5.37	95.1	380.3		
	10-20	5.75	0.72	4.14				
Pasture *Dystric Leptosol*, second sampling								3
P8Ss	0-10	6.73	0.91	6.1	163.2	652.9	532.7	
	10-20	8.36	1.22	10.2				
P1OSs	0-10	7.60	0.68	5.2	128.4	513.6		
	10-20	5.60	1.37	7.7				
PISs	0-10	6.71	0.83	5.6	107.9	431.5		
	10-20	6.14	0.85	5.2				

*n.a. = not applicable; **n.d. = not defined

5.2.1.1 SOIL ORGANIC CARBON DENSITY (SCD) FOR SAMPLING SITE

The calculation of the SCD follows eq. 1 (hereafter the numeration of equations follows the section that described the algorithms). The SCD refers to carbon concentration in $\left(\frac{kgC}{m^2}\right)$ or $\left(\frac{tC}{ha}\right)$ related to a layer of soil (e.g., 0-0.3 m, 0-0.5 m, 0-1.0 m, 0-2.0 m). The SCD should not be confused with the carbon (C) content of soil. The latter is a relative fraction of C by weight of soil expressed in percentage $\left(\frac{kgC}{kgSoil}X100\right)$. This value does not show an absolute C mass in soils and is inconvenient to use for soil comparisons. The mass of C dependence on the soil bulk density (e.g., soil with a low percent of C and high value of bulk density may contain more mass of C than soil with a high content in C and low value of bulk density).

The example for the calculation of the SCD is given for the *Skeletic Cambisol* cropland (site C1S, Table 5) in the Piemonte region. The soil has the following measured parameters:

$SOC_{content}$ is 2.43 %;

BulkDensity is 1.29 kg/dm^3;

Depth of ploughed layer is 2.5 dm (0-25 cm);

frag is none.

Introduction of these parameters into eq. 1 gives:

SCD = 2.5 (dm) X 2.43 (kgC/kgSoilX100) X 1.29 (kgSoil/dm^3) X 100 = 7.86 kgC/m^2,

where units are given in brackets and, 100 is to converted dm^2 into m^2.

5.2.1.2 MEAN (ARITHMETIC AVERAGE) SOIL ORGANIC CARBON DENSITY ($\overline{SCD}_{plot}$) FOR PLOT

The calculation of the mean $\overline{SCD}_{plot}$ follows eq. 2. For the above-mentioned cropland *Skeletic Cambisol*, values of the SCD for the three identified sampling sites were defined as 7.86 kgC/m^2; 7.72 kgC/m^2 and 7.00 kgC/m^2 (Table 5).

The introduction of these values in to eq. 2 gives:

$\overline{SCD}_{plot}$ = (7.86+7.72+7.00)/3 = 7.53 (kgC/m^2) or 75.3 (tC/ha)

5.2.1.3 SOIL ORGANIC CARBON STOCK (SOC_{stock}) FOR PLOT

Calculation of the SOC stock follows eq. 3. The SOC stock refers to the total amount of C captured by a certain layer of soil having a certain area. The SOC stock is named "reference" for the initial (first time) sampling. For the cropland *Skeletic Cambisol,* the ploughed layer is 0.25 m, which is accounted by the eq.2. The area of the tested cropland is 6.96 ha. The introduction of these values in to eq. 3 gives:

$SOC_{reference}$ = 75.3 (tC/ha) X 6.96 (ha) ~ 524.1 (tC)

5.2.2 Changes of soil organic carbon stock (ΔSOC)

As explained in the preceding section, time series observations are needed to detect changes of SOC stock. Our tests do not have these data. Nevertheless, an opportunity was exploited to simulate the SOC stock change to samples collected in the forest test site. The planting scheme in the forest follows rows in which the rows with trees are covered by a dark plastic sheet isolating soil from litter. The rows without trees are lacking plastic sheet and open to littefall. This makes the input of organic residuals in soils different and causes a difference in the SOC content between the covered (with trees) and bare rows. The sampling template was designed in such a way that the first set of samples was collected from the rows with trees and the second set of samples from bare soil. The two sets are examined to define the difference between SOC stocks in the forest plot, which is interpreted as a SOC stock change. In order to simplify the calculations the area of the forest plot is taken as 4 ha.

Table 6. Difference in soil organic carbon contents between rows with trees (covered by plastic sheet) and rows without trees open to litterfall in the forest plot.

ID	Soil carbon density by sites, tC/ha	Mean soil carbon density for forest, tC/ha	Soil carbon stocks (4ha forest plot), tC	Difference (changes) in soil carbon stocks, tC
Rows with trees covered by plastic sheet				108.4
F27S	50.68			
F31S	47.51	45.3	181.2	
F35S	37.75			
Rows with bare soil open to litterfall				
F27Ss	74.1			
F31Ss	70.2	72.4	289.6	
F35Ss	72.9			

Table 6 illustrates the calculation of the difference in the SOC stock following the eq. 4:

$$\Delta SOC_{forest} = \left|289.6 - 181.2\right| = 108.4 \text{ (tC)}$$

5.2.3 Standard error of the changes of soil organic carbon (SOC) stock

An example of the calculation of the standard error for the difference between SOC stocks in rows with trees and that with bare soils is given in Table 7.

Table 7. The standard error of the difference (changes) of the SOC stocks (tC ha).

First sampling	Second sampling	Difference (ΔSOC_{site})	Average of differences ($\Delta SOC_{site}/3$)	Standard error of the differences ($s(\Delta S\overline{C}D_{site})$)	Standard error of the changes estimate for the forest plot (4ha) ($s(\Delta S\overline{C}D_{site}) \times 4$)
50.68	74.1	23.42	27.01	4.03	~16.1
47.51	70.2	22.69			
37.75	72.9	35.15			

The calculation of the error uses eq. 5 (in the uncertainty section). The values for the calculations are given in Table 7.

$$s(\Delta S\overline{C}D_{site}) = \sqrt{\frac{1}{3(2-1)}\sum_{site=1}^{3}((74.1-50.68)-27.1)^2 + ((70.2-47.51)-27.1)^2 + ((72.9-37.75)-27.1)^2} = 4.03$$

(tC)

5.2.3.1 Standard error of soil organic carbon stock changes ($s(\Delta SOC_{stock})$) for forest plot

The standard error of the difference for the forest plot follow eq. 6:

$s(\Delta SOC_{stock}) = 4.03 \times 4 = 16.12 \approx 16.1$ (tC)

5.2.3.2 Result of the verification of soil organic carbon stock changes (ΔSOC_{stock}) for forest plot

The overall result will be in line with eq. 7:

$$\Delta SOC_{stock} = 108.4 \pm 16.1 \text{ tC}$$

5.2.4 Reproducibility of the sampling results

The test of the RP is based on the parameters defined for cropland and pasture (Table 5). From Table 5, these parameters cover all measurements essential to calculate the SOC stock in cropland and pasture soils. The SOC stock varies in the range from 280 tC (C22Ss site) to 314 tC (C1S site) in cropland *Gleyic Luvisol*s and from 380 tC (PIS site) to 724 tC (P8S site) in the pasture *Dystric Leptosol* Based on these data, the RP is computed using eq. 8:

$$RP_{cropland} = \frac{(301.1 - 292.0)}{301.1} \times 100 \approx 3\,\%$$

while the calculation for the pasture gives:

$$RP_{pasture} = \frac{(532.7 - 516.2)}{516.2} \times 100 \approx 3\,\%$$

The comparison of the RP between cropland and pasture shows that in spite of the considerable variation in SOC contents in soils of cropland (9%) and pasture (15%) (Table 8), the AFRSS method provides a RP value at practical level (within 3%) illustrating applicability of the method to wide range of soil conditions.

Table 8. Average soil organic carbon content and its variation in the tested plots.

Land use	Number sites	Average C, %	Coefficient of variation, %
Cropland	5	2.13	9
Pasture	12	6.71	15
Forest	12	1.55	23

5.3 Economic effectiveness

5.3.1 Number of samples

The cost of the sampling to assess SOC consists of different components which include the number of samples collected and the laboratory price to determine the SOC content. In this study, cost comparisons for the conventional IPCC (IPCC, 2003) and the AFRSS sampling approaches are made. The IPCC procedure recommends that nine soil points are tested for each plot, each containing three sampled depths (0-10 cm, 10-20 cm and 20-30 cm). These samples are required to study the spatial variability of the soil parameters for the initial sampling. On the basis of these data, the number of the soil samples needed for a second sampling is estimated. IPCC propose to detect the changes in the SOC stock with a confidence level of 95%.

The CV of SOC content in the soil of the cropland, pasture and forest are 9%, 15% and 23% respectively (Table 8). If the value $CV(SOC) = 0.09$ (i.e. 9% SOC stock) is taken, as an example, then the standard error of the measured average SOC is

$s(\overline{SOC}) = 0.09 \times SOC$. The values for pasture and forest plots will be: $s(\overline{SOC}) = 0.15 \times SOC$ and $s(\overline{SOC}) = 0.23 \times SOC$ respectively.

Thus, to calculate the required number of samples needed to estimate the SOC with a confidence semi-interval of 1.5 tC/ha (suggested average annual C accumulation in agricultural soil in Europe, corresponding to approximately 2% of the average SOC) and with a 95% confidence level, the coefficient of variation of the estimate is required to be:

$$CV(\overline{SOC}) = \frac{s(\overline{SOC})}{\overline{SOC}} = \frac{0.02}{t_{95}} \quad \Rightarrow \quad s(\overline{SOC}) = \frac{0.02 \times \overline{SOC}}{t_{95}},$$

where $t_{95} = 1.96$ (as taken from Student's t Table) if the sample size is large enough but can be above 2 for a moderate sample size, especially if the distribution of SOC is not Gaussian. For a lower confidence level $t_{65} \approx 1$ or $t_{90} \approx 1.7$ if the distribution of SOC is assumed to be normal.

In a simple random sampling, the standard deviation of the SOC estimate is:

$$s(\overline{SOC}) = \frac{s(SOC)}{\sqrt{n}}$$

Therefore, the required sample size to achieve certain accuracy with a given confidence level with simple random sampling in the cropland is:

$$n = \left(\frac{CV(SOC) \times SOC}{s(\overline{SOC})}\right)^2 = \left(\frac{CV(SOC) \times SOC \times t_{95}}{0.02 \times \overline{SOC}}\right)^2 \approx \left(\frac{CV(SOC) \times t_{95}}{0.02}\right)^2 \approx \left(\frac{0.09 \times 2}{0.02}\right)^2 = 81$$

Figure 7 illustrates the considerations in general form for the average soil conditions of Europe. For example, the range of SOC density varies from 50 to 100 tC/ha and average change of carbon in soil is 1.5 tC/ha. The figure shows that in order to meet the IPCC requirements the amount of the samples is rather large even for relatively homogeneous soil (e.g. CV for cropland soil is 9%). This amount should be further increased by a factor of 3 because of the recommendation by IPCC 3 layers sampling of the 30 cm topsoil. This multiplication results in 243 samples in total for cropland, 675 samples for pasture and 1587 samples for forest (Table 9).

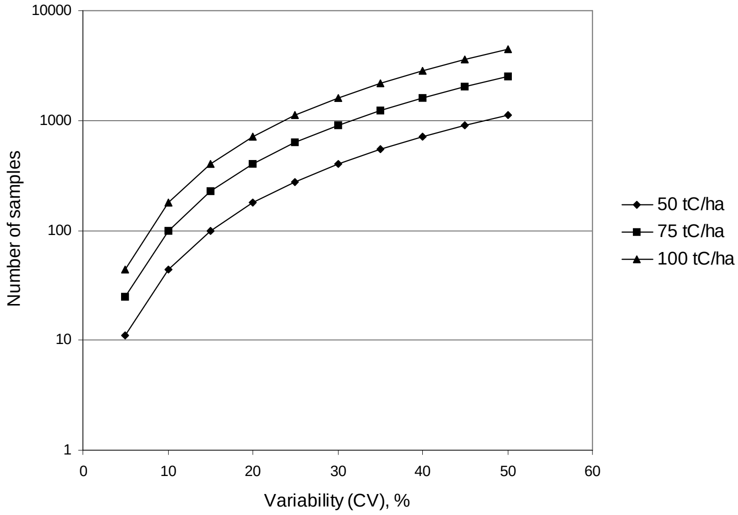

Figure 7. Number of samples for simple random sampling depending on the SOC variability and the average SOC (minimum detectable changes of 1.5 tC/ha, 95% confidence).

5.3.2 Laboratory costs

Multiplying the number of samples by the cost of the analysis of one sample calculates the total cost of the laboratory treatment. For example, the price to determine C in commercial laboratories in Europe varies from €6 to €16, where the lowest price (€6) is taken from CARBOEUROPE project (see www.carboeurope.org) and highest price (€16) is indicated by EU BIOSOIL project (see http://inforest.jrc.it/activities/ForestFocus/biosoil.html). If a 4 ha plot area is considered and the amount of accumulated C is assumed to be 6 tC, then the cost of the analysis for one tonne of accumulated C will range from €241 to €643 tC for cropland, from €675 to €1800 tC and from €1587 to €4332 tC for pasture and forest respectively (Table 9). Clearly, these high costs make the routine measurement of C changes in soil impractical with the risk that the role of soil in carbon management issues will not be considered by policy and decision makers.

The laboratory costs for the application of the AFRSS is different. Firstly, the number of samples is considerably less. The detection of carbon in the cropland and pasture plots needs only to analyse three samples for the area of 4 ha (see Table 1). Thus, the cost of the analysis will range from €3 to €8 tC depending on the laboratory prices mentioned above. The detection of carbon levels in the forest plot requires the analysis of six samples for a 4 ha area (see Table 1) including three samples of the litter and three samples of the mineral soil. The cost of the analysis will range from €6 to €16 tC. Table 9 shows that the analysis cost provided by AFRSS is practically feasible, especially, if these costs are recalculated to tCO_2_eqv. For this computation, the costs in Table 9 are subdivided by factor of 3.67, which is the conversion coefficient from C to CO_2 units. For example, the cost of analysis in one tCO_2_eqv will be in the range of €0.82 - €2.18 for cropland and pasture and in the range of €1.64 - €4.40 for forest.

Table 9. The laboratory costs of carbon detection. Conditions: the average carbon change is 6 tC for the 4 ha plot; the laboratory price of the carbon determination is in the range €6-16 per sample.

Land cover	Conventional (IPCC, 2003)			Area-Frame Randomized Soil Sampling		
	Variability, %	Number of samples	Cost per tC	Variability, %	Number of samples	Cost per tC
Cropland	9	241	241-643	n.a.*	3	3-8
Pasture	15	675	675-1800	n.a	3	3-8
Forest	23	1587	1587-4232	n.a.	6	6-16

*n.a. = not applicable

5.3.3 Effect of the plot area on laboratory cost

Figure 8 provides a tentative cost of determining carbon in the laboratory depending on the area of the plot. From the figure, the laboratory costs decreases with an increase of the size of the sampling plot (e.g., the cost to detect 1 tC in a field of 1 ha is nearly €35). This cost will be about €0.13 in an arable field of 50 ha.

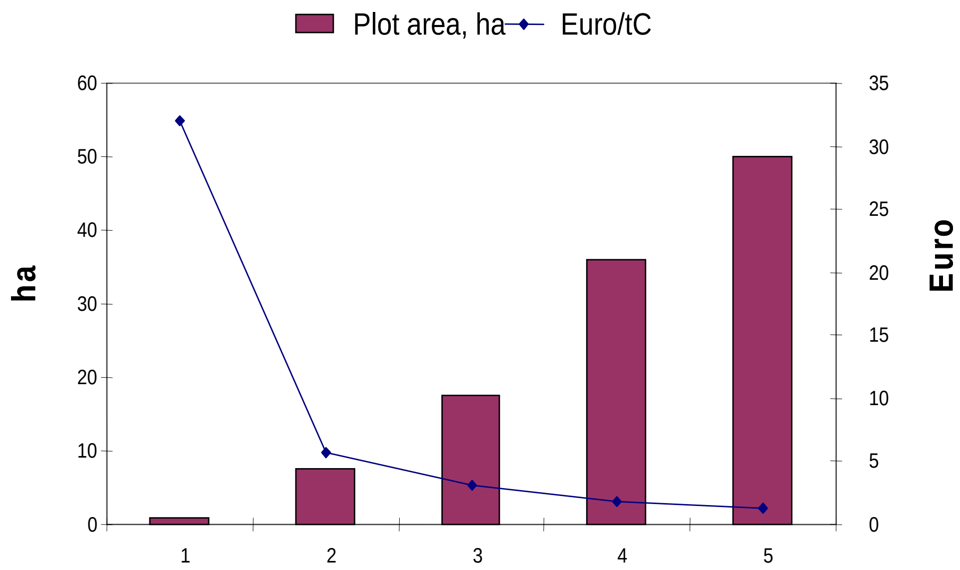

Figure 8. Dependence of the laboratory cost for carbon determination on the plot area. Conditions: average carbon sink in agricultural soils is 1.5 tC/ha; the cost of carbon determination in laboratory is 16 Euro.

5.4 Applicability of organic carbon stock in soil for carbon management

According to certain publications (e.g. Batjes, 1996), the variability of the SOC stock is large, which can lead to doubts in the minds of politicians and practitioners for the implementation of SOC management procedures. The assumption is that if the uncertainty of the SOC stock detection is large at the initial (first time) sampling, then the verification of SOC stock changes at the subsequent time sampling would be even more biased and less confident. For instance, the second sampling will assimilate the errors of both sampling campaigns. However, this assumption is a provisional and is based on general considerations which need to be checked against data from field experiments. Data from the studies described in this document can contribute to this discussion with respect to the uncertainty of SOC detection. Specifically, this study contributes to the analysis of how the deviation of the $S\overline{O}C$ stock depends on their value.

Figure 9 shows that the $S\overline{O}C$ stocks and their average deviation are different for different plots. This depends mainly on variation in soil types between the tested plots (e.g. *Skeletic Cambisol* (cropland), *Dystric Leptosol* (pasture) and *Gleyic Luvisol* (forest)). The difference in principle soil characteristics among these soils are clearly observed in Table 5 and soil characterization (Annex 1).

The variability in the SOC stocks in cultivated *Skeletic Cambisol* (Figure 9a) is lower then in *Dystric Leptosol* (pasture) and *Gleyic Luvisol* (forest) because of the historical selection of the relatively homogeneous and more suitable soils for cropping. The relatively higher variation of the $S\overline{O}C$ stock is caused by the initial heterogeneity in soils of both Alpine pastures and forests.

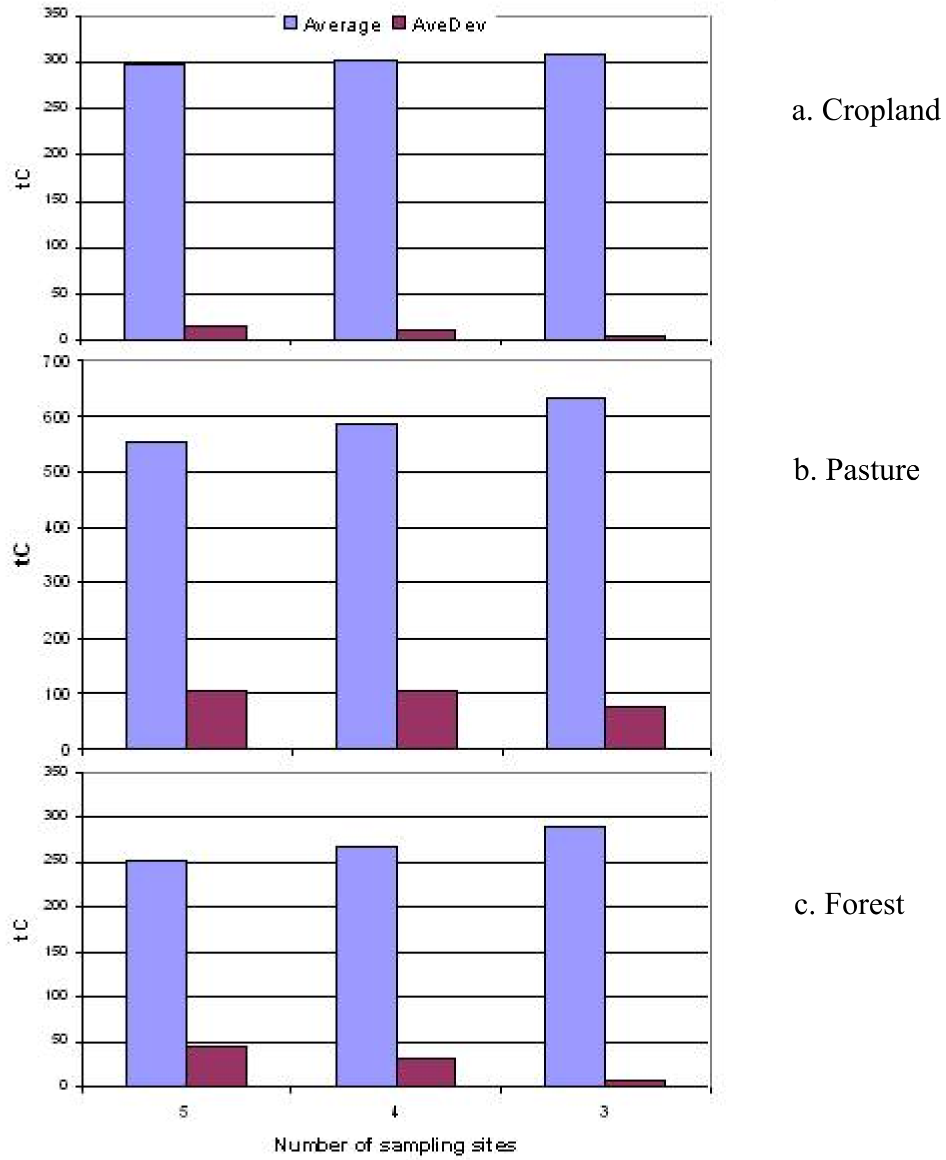

Figure 9. Average soil organic carbon stock (Average) in tC and deviation in the average (AveDev) for: a) Cropland, b) Pasture and c) Forest plots. The thicknesses of the layers are: ploughed horizon = 25 cm, pasture topsoil = 30 cm; forest soil litter plus 20 cm mineral topsoil. The area of the plots is 4 ha.

Figure 9 shows that all tested soils follow a common pattern: the deviation of the $\overline{SOC}$ stocks is less in the soil having higher SOC content. This analysis allows for the conclusion that the uncertainty of SOC stock verification expects to be less where the soil will experience enrichment of the SOC stock due to implementation of the C enhancement measures.

In conclusion, the study illustrates that implementation of soil in land-based carbon management is feasible. The cost and uncertainty of the verification of the SOC changes in mineral soils should not be considered as a constraint for this practice.

Annex 1 Description of the tested plots

Cropland

Geographic distribution and pedo-landscape

The soil type is characteristic of virtually level alluvial cones, formed by gravelly and coarse sandy deposits, with a deep groundwater table where its effects on the soil hydrology are not evident. The parent material is not calcareous but rich in greenstones. The land use is mainly agricultural with prevalence of rotated cultivations and grasslands.

Soil series: FOGLIZZO coarse-loamy over sandy-skeletal, gravely.

Soil properties: soil is characterised by a loamy or silty-loam texture and by a low macro porosity due to iron oxides (mottling and concretions). Consequently, drainage as well as oxygen availability is moderate. The main feature is a root restricting depth at 45-50 cm due to very gravely layers. Saturated hydraulic conductivity is moderately high, influenced by coarse texture and gravels

Profile: brown topsoil, sandy-loam, 15% gravel, acid or subacid pH; yellowish brown subsoil with some reddish shade, sandy-loam with gravel over 35%, subacid pH. The substratum is constituted of gravels and sands. Ca/Mg ratio is lower due to greenstones and reduces soil chemical fertility.

Profile code: LIQU0050

Profile location: Malanghero (S.Maurizio – province of Turin)

Profile classification:

Soil Taxonomy***:*** *Dystric Eutrudept, coarse-loamy over sandy-skeletal, mixed, nonacid, mesic*

WRB: *Skeletic Cambisol*

Slope: 0°

Exposition: no.

Elevation: 230 m a.s.l.

Land use: rotated wheat

Lithology: fluvio-glacial deposits

Morphology: alluvial plain

Photo: the soil profile LIQU0050, characterized by sandy-loam texture with the presence of pebbles from alluvial gravel deposits of the River Stura clearly evident**.**

Photo: the plot site from a satellite image

Layer Ap: 0 - 25 cm; dark brown (10YR 3/3); sandy-loam; 25 % gravels, of rounded shape, with average diameter 30 mm and maximum diameter 150 mm, slightly altered; structure fine granular of moderate degree; roots 20/dmq, with average dimensions 3 mm; non calcareous.

Layer A2: 25 - 45 cm; dark yellowish brown (10YR 3/4); sandy-loam; 35 % gravels, of subrounded shape, with average diameter 40 mm and maximum diameter 150 mm, slightly altered; structure subangular medium poliedric of moderate degree; roots 5/dmq, with medium dimensions 2 mm; non calcareous.

Layer Bw: 45 - 65 cm; dark yellowish brown (10YR 3/4); sandy-loam; 70 % gravels, of subrounded shape, with average diameter 60 mm and maximum diameter 200 mm, slightly altered; structure incoherent; roots 2/dmq, with average dimensions 2 mm, non-calcareous.

Layer C1: 65 - 90 cm; dark yellowish brown (10YR 3/6 and 10YR 3/5); loamy-sand; 70 % subrounded gravels, with average diameter 100 mm and maximum 300 mm, altered; structure: weak; non calcareous.

Layer C2: 90 - 120 cm; brown (10YR 5/3); secondary colour yellowish brown (10YR 5/6); mottles very dark gray (10YR 3/1); loamy-sand; 90 % subrounded gravels, with average diameter 150 mm and maximum 350 mm; structure weak; non calcareous.

Physical-chemical analyses of the *Skeletic Cambisol* (cropland soil profile)

	Ap	A2	Bw	C1
Upper boundary cm	10	30	45	65
Lower boundary cm	20	40	55	80
pH in H2O	5,5	5,4	6,1	6,4
Coarse sand %	20,6	24,3	35,6	75,5
Fine sand %	32,6	32,9	34,3	14,2
Very fine sand %	-	-	-	-
Coarse silt %	18,9	15,1	13,0	3,9
Fine silt %	23,9	24,0	14,4	5,3
Clay %	4,0	3,7	2,7	1,1
CaCO3 %	0,0	0,0	0,0	0,0
Organic carbon %	2,69	2,34	1,45	1,03
N %	0,259	0,252	0,129	0,101
C/N	10,0	9,0	11,0	10,0
Organic matter %	0,00	0,00	0,00	1,77
C.S.C. meq/100g	18,20	18,40	6,90	15,30
Ca meq/100g	4,75	4,12	2,98	1,30
Mg meq/100g	3,08	2,83	2,58	2,29
K meq/100g	0,36	0,27	0,16	0,09
Na meq/100g	0,18	0,15	0,20	0,15
P available ppm	51,0	39,0	23,0	25,0
Basic saturation %	-	-	-	-

Pasture

Geographic distribution and pedo-landscape

The test site is located at the head of the Tesso Valley, representative of glacial relief from the last ice age. Around the glacial cirque occupied by Lake Monastero, moraine accumulations and outwash features are found.

Soil series

Not defined

Soil properties

The site is characterized by an alternation of deeper soil with an A-AB-Bw-BC-C layers sequence and shallow soil, characterized by the presence of only two layers: the first is few centimeters deep and in rich in organic matter while the second is the interface with the rocky substratum. The pedon is characterized by a high anisotropy due to variability of micro-relief which brings different depth and percentage of rock fragments. Consequently, the herbaceous cover and root development are to be considered irregular in depth and quantity.

Profile

A sequence of three layers Ah-BC-C. Layer Ah is brown (10YR 4/2); loamy-sand; 2% of rock fragments; fine structure of granular shape Layer BC is brown (10YR 4/3); loamy-sand; 25 % of rock fragments, of irregular shape. Layer C is dark brown (10YR3/3), sandy, 60% of rock fragments.

Profile code: LANZ0069

Profile location: Slope and ridge morphologies, Lake Monastero, alpine lake,

Profile classification:

USDA: *Lithic Cryorthent, coarse-loamy, mixed, acid, frigid*

WRB: *Dystric Leptosol*

Slope: 30°

Exposition: 270°

Elevation: 230 m a.s.l.

Soil use: alpine pasture

Lithology: elluvium of serpentine

Morphology: slopes with rocky ledges

Layer Ah: 0 -10 cm, humid, dark greyish brown (10YR 4/2), secondly very dark greyish (10YR 3/2); loamy-sand; 2% irregular skeletal; fine structure of granular shape and moderate strength; common macro pores of medium dimensions 1-5 mm; roots 40/dmq, of medium dimensions of 1 mm and maximum dimensions of 3 mm, oriented in every plane; rooting 90%; consistence: slightly resistant; very slightly cemented; non-sticky; non-plastic; non- calcareous; no concentrations ; no coats; lower boundary clear and wavy

Layer BC: 10 -20 cm; humid; brown (10YR 4/3); loamy-sand; 25 % of rock fragments, of irregular shape, with 10 mm of medium diameter and 100 mm of maximum diameter, highly altered; fine subangular polyedric structure of moderate strength; few macropores, with medium dimensions of less than 1 mm; roots 5/dmq, of medium dimensions of 1 mm and maximum dimensions of 2 mm, oriented in horizontal planes; rooting 60 %, consistence: slightly resistant; very slightly cemented; non-sticky; non-plastic; non- calcareous; no concentrations ; no coats; lower boundary clear and wavy

Layer C: > 20 cm; humid; dark brown (10YR 3/3); sandy; 60 % of rock fragments, of irregular shape, with 10 mm of medium diameter and 300 mm of maximum diameter, highly altered; incoherent structure; few macropores, , with medium dimensions of less than 1 mm; no roots; rooting 30%; consistent: slightly resistant; very slightly cemented; non-sticky; non-plastic; non- calcareous; no concentrations ; no coats; lower boundary: unknown.

Physical-chemical characteristics of the *Dystric Leptosol* (pasture soil profile)

	Ah	AB	Bw	BC
Upper boundary cm	0	10	35	70
Lower boundary cm	10	35	70	120
pH in H_2O	4,4	4,6	5,0	5,1
Gravel %	2	10	10	25
Coarse sand %	29,4	39,8	38,9	50,1
Fine sand %	51,6	28,2	28,6	32,4
Coarse silt %	10,8	8,9	8,0	8,2
Fine silt %	6,0	16,2	17,2	7,6
Clay %	2,1	7,0	7,2	1,7
$CaCO_3$ %	0,0	0,0	0,0	0,0
Organic carbon %	6,90	1,18	0,92	2,74
N %	0,416	0,138	0,098	nd
C/N	17	8,6	9,4	nd
Organic matter %	11,87	2,04	1,58	4,71
C.S.C. meq/100g	17,56	9,32	10,26	nd
Ca meq/100g	1,06	0,12	0,10	nd
Mg meq/100g	0,50	0,17	0,07	nd
K meq/100g	0,04	0,02	0,01	nd
P available ppm	17,6	nd	nd	nd
Basic saturation %	9	3	2	nd

I

Photo: profile LANZ0069 in the maximum depth

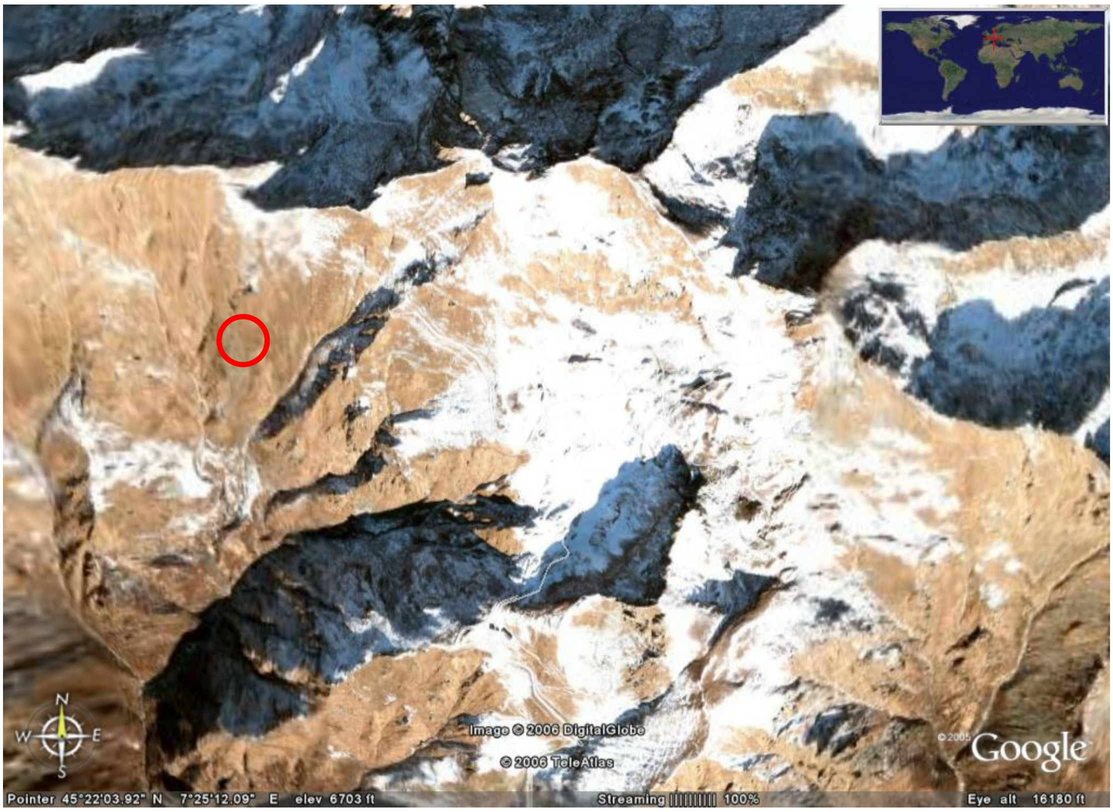

Photo: satellite image of the mountain site morphology. Study area is indicated by the red circle.

Forest

Geographic distribution and pedo-landscape
The main soil type is a Luvisol (WRB), which covers the lower level of the old river terrace in the Partecipanza of Trino (Vercelli province). Irregular surface constituted by eroded parts of an old terrace formed on a substratum made by gravely deposits rich in fine sands and, secondly, by clay. The sampling site is located at 150 m a.s.l., 20 m higher than the surface of the main plain. The original slopes are almost unrecognizable due to the arrangement of rice-chambers. Surface stoniness is very low. Land use is rice-growing.

Soil series: Ramezzana. fine-silty

Soil properties: the soil is characterised by a loamy or silty-loam texture and by a low macroporosity due to iron oxides (mottling and concretions). Consequently, drainage as well as oxygen availability is moderate. Soil variability is sharpened by two factors: irregular distribution of organic matter due to plastic sheets used in wood arboriculture and irregular patterns of soil texture and bulk densities due to mixing of soil layers in rice-field arrangements for water submersion.

Profile: is composed by a loamy topsoil with acid pH, often conditioned by sub merged cultivation,, and by a subsoil constituted by a sequence of eluvial-illuvial layers with loamy texture, neutral pH and evidence of clay coats. Below 160 cm C layers are well recognisable with much more gravel and colours vary from olive-brown to yellowish-brown with evident mottles all along the depth.

Profile code: ASTA0006

Profile location: Crescentino (province of Vercelli)

Profile Classification:

Soil Taxonomy**:** *Aquic Haplustalf, fine-silty, mixed, nonacid, mesic*

WRB: *Gleyic Luvisol*

Slope: 0°

Exposition: - °

Elevation: 160 m slm

Land use: rice-growing

Lithology: silty fluvio-glacial deposits

Morphology: lower part of ancient terrace

Photo: the soil profile of a rice-field near the Trino arboricolture plot

Photo: the arboriculture plot of Trino (VC)

Layer Ap1 : 0 - 7 cm; humid, light olive brown (10YR 3/1); loamy; 15% of mottles (4 mm medium size) with clear boundaries, dominant colour yellowish brown (10YR5/6), secondary colour greenish gray (1 for gley 6/3); non gravely, clod structure, few macropores (less than 1 mm medium size), no roots, rooting 90%, consistence: moderately resistant; very slightly cemented; slightly sticky; moderately plastic; non- calcareous; no concentrations ; no coats; lower boundary clear and wavy.

Layer Ap2:15 - 30 cm; humid, greenish gray (1 FOR GLEY 5/3), color type: redacted; loamy;; non gravelly, clod structure, few macropores (less than 1 mm medium size), no roots, rooting 90%, consistence: moderately resistant; very slightly cemented; slightly sticky; moderately plastic; non- calcareous; no concentrations ; no coats; lower boundary clear and wavy.

Layer EB: 30 - 60 cm; humid; light olive brown (2,5Y 5/4); colour type: variegated; mottles: quantity 25%, average size 7 mm, clear boundaries, primary yellowish brown (10YR 5/6), secondary light brownish gray (2,5Y 6/2); other mottles: dark yellowish brown (10YR 4/4); loamy; non gravely; structure: massive; common macropores of 1-5 mm medium size; rooting 50%; consistence: very slightly cemented; slightly sticky; moderately plastic; non- calcareous; 5 % iron-manganese nodules, 2 mm medium size in the matrix; lower boundary gradual and smooth.

Layer Bt1: 60 - 100 cm; humid; dominant colour yellowish brown (10YR 5/4); secondary colour dark yellowish brown (10YR 4/4); colour type: variegated; mottles: quantity: 25 %, average size 5 mm, clear boundaries, primary light brownish gray (2,5Y 6/2), secondary yellowish brown (10YR 5/6); loam; non gravely; weak structure with coarse subangular polyedric shape; many macropores, with average dimensions greater than 5 mm; rooting 50%; consistence: slightly resistant, very slightly cemented; moderately sticky; slightly plastic; non calcareous; 4 % iron-manganese nodules, 2 mm medium size in the matrix; 3 % iron-manganese masses, with average dimensions 15 mm, in the matrix; 2% clay coats in the matrix; gradual and linear lower boundary.

Layer Bt2: 100 - 160 cm; humid; light olive brown (2,5Y 5/3); peds faces brown (7,5YR 4/4); colour type: variegated; mottles: quantity: 20 %, average size 4 mm, abrupt boundaries, primary light brownish gray (2,5Y 6/2), secondary yellowish brown (10YR 5/6); loam; non gravely; weak structure with medium angular polyedric shape; common macropores, with average dimensions greater than 5 mm; rooting 30%; consistence: slightly resistant, very slightly cemented; slightly sticky; slightly plastic; non calcareous; 2 % iron-manganese nodules, 2 mm medium size in the matrix; 2 % iron-manganese masses, with average dimensions 2 mm, in the matrix; 20% clay coats in the matrix; gradual and linear lower boundary.

Layer C: 160 - 170 cm; humid; gravel 70 %, of subrounded shape, with average diameter 50 mm and maximum 80 mm, very much altered.

Physical-chemical characteristics of the *Gleyic Luvisol* (forest soil profile)

	Ap1	Ap2	EB	Bt1	Bt2
Upper boundary cm	0	20	40	80	130
Lower boundary cm	10	30	50	90	140
pH in H2O	6,5	6,4	7,6	7,2	7,0
Coarse sand %	3,4	3,3	5,1	6,5	13,0
Fine sand %	20,1	20,0	3,1	5,9	6,7
Very fine sand %	-	-	22,6	21,5	25,7
Coarse silt %	32,0	32,5	27,0	28,1	22,0
Fine silt %	27,9	26,7	19,3	18,2	15,2
Clay %	16,7	17,7	23,0	19,8	17,4
CaCO3 %	0,0	0,0	0,0	0,0	0,0
Organic carbon %	1,20	1,30	-	-	-
N %	0,148	0,156	-	-	-
C/N	8,1	8,3	-	-	-
Organic matter %	2,06	2,24	-	-	-
C.S.C. meq/100g	20,00	18,60	-	-	-
Ca meq/100g	6,60	6,55	-	-	-
Mg meq/100g	1,58	1,58	-	-	-
K meq/100g	0,51	0,38	-	-	-
Na meq/100g	-	-	-	-	-
P available ppm	10,5	9,1	-	-	-
Basic saturation %	44	46	-	-	-

Annex 2 Terms and definitions

Accuracy: a relative measure of the exactness of the soil organic carbon change estimate.

Carbon Certification: a process where a written quality statement (a certificate) attesting the amount of organic carbon stock in soil and its changes due to land-based activities.

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

Cropland: arable or tilled land and agro-forestry systems where vegetation characteristics falls below the threshold used to define the forest land category, consistent with the selection of national definitions.

Forest land[11]: *land with* 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 document. Forest land also includes systems with vegetation that currently falls below, but is expected to exceed, the threshold of the forest land category.

LULUCF: Land Use Land Use Change and Forestry, a term used in IPCC reports.

Mineral soil material: 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
   - 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.

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[11] *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.

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 the field, pasture or forest plot.

Sampling site: a location within a field, pasture or forest plot at which physical soil sampling takes place.

Soil profile: a location within a field, pasture or forest plot at which a soil pit is dug and where a soil description is made and undisturbed samples are taken.

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Abstract

This report updates the "Soil Sampling Protocol to Certify the Changes of Organic Carbon Stock in Mineral Soil of the European Union" published in 2005. The revision is based on the field testing of the Protocol and on the analysis of the users comments. The revised Protocol is illustrated by examples of the application of the methodology and computation routines.

The study reveals that new Area-Frame Randomized Soil Sampling allows for measurable, transparent and cost-effective verification of the soil organic carbon changes in mineral soil. This makes soil implementation in land-based carbon management in the European Community feasible. The results show that uncertainty of the verification of the soil organic carbon changes in mineral soil is less for the soil richer in carbon after the carbon enhancement measurements have been applied.

This study was fulfilled within the SOIL Action of the European Commission's DG Joint Research Centre's Land Management and Natural Hazards Unit (part of the JRC's Institute for Environment and Sustainability). The work was carried as part of the FP6 funded (contract no: 503614 (INSEA)) Integrated Sink Enhancement Assessment STREP Project, led by the International Institute for Applied Systems Analysis (IIASA, Vienna).

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