VALIDATION OF THE EU SOIL SAMPLING PROTOCOL TO VERIFY THE CHANGES OF ORGANIC CARBON STOCK IN MINERAL SOIL (PIEMONTE REGION, ITALY)

Vladimir Stolbovoy[1], Nicola Filippi[1], Luca Montanarella[1], Mauro Piazzi2, Fabio Petrella [2], Javier Gallego [3], Senthil-Kumar Selvaradjou[1]

[1] EC Joint Research Centre, Land Management and Natural Hazards Unit
[2] Soil Department, Institute for Forestry and Environment (IPLA)
[3] EC Joint Research Centre, Agrifish Unit

EUROPEAN COMMISSION
DIRECTORATE-GENERAL
Joint Research Centre

2006

EUR 22339 EN

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Stolbovoy[1] Vladimir, Nicola Filippi[1], Luca Montanarella[1], Mauro Piazzi[2], Fabio Petrella [2], Javier Gallego [3], Senthil-Kumar Selvaradjou[1]

[1] Land Management and Natural Hazards Unit, Joint Research Center EC
[2] Soil Department, Institute for Forestry and Environment (IPLA)
[3] Agrifish Unit, Joint Research Center EC

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European Commission
Joint Research Centre (DG JRC)
Institute for Environment and Sustainability (IES)
Land Management and Natural Hazards Unit
I-21020 Ispra (VA), Italy
Tel: 0039-0332-785574;
Fax: 0039-0332-786394

E-mail: panos.panagos@jrc.it , luca.montanarella@jrc.it , vladimir.stolbovoy@jrc.it
Website: http://ies.jrc.cec.eu.int/, http://eusoils.jrc.it

EUR 22339 EN

Printed in Italy

This document may be cited as follows:

Stolbovoy Vladimir, Nicola Filippi, Luca Montanarella, Mauro Piazzi, Fabio Petrella, Javier Gallego, Senthil-Kumar Selvaradjou (2006). Validation of the EU soil sampling protocol to verify the changes of organic carbon stock in mineral soil (Piemonte region, Italy), EUR 22339 EN, 41pp. Office for Official Publications of the European Communities, Luxembourg.

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http://eusoils.jrc.it

Acknowledgements

This work was fulfilled within Sixth Framework Programme in the frame of the Integrated Sink Enhancement Assessment project funded by EC Contract No SSP1-CT-2003-503614-INSEA and carried out by the MOSES (Monitoring the State of the European Soils) action No 2132 of the Institute for Environment and Sustainability of the JRC EC (Ispra, Italy). More information about the study can be found in the Home address: http://eusoils.jrc.it

We gratefully acknowledge the support of Roberto Salandin and the contributions of his colleagues who helped us to complete the numerous tasks in the field research and laboratory analysis at the *Istituto per le Piante da Legno e l'Ambiente S.p.A. - Settore suolo, Regione Piemonte*.

Special thanks go to Arwyn Jones who helped us to edit the document.

Table of Contents

Acknowledgements iii
Table of Contents iv
Introduction 1
Method background 2
  Template description 2
  Adaptation of the template 4
  Sampling location 4
  Pedological considerations of the sampling 5
    Cropland 5
    Pasture 6
    Forests 6
  Algorithms 7
  Computation 7
  Uncertainty 9
  Reproducibility 10
Field validation 11
  Cropland 11
    Adaptation of the template 12
  Pasture 14
    Adaptation of the template 14
  Forest 15
    Adaptation of the template 16
Materials 17
Discussion 19
Economic effectiveness 23
  Laboratory costs 23
  Effect of the plot area on laboratory cost 26
Conclusions 26
References 27
Annex 1 Description and laboratory data on soil 30
  Cropland plot 30
  Pasture plot 34
  Forest plot 38

Introduction

Soil organic carbon (SOC) is a measure of the total amount of organic compounds or carbon (C) in soil independently of their origin or decomposition. Interest in SOC is common among soil scientists and related practitioners because of its importance for principle physical, chemical and biological soil ecological functions and that SOC is a universal indicator of soil quality. Consequently, variations in levels of soil organic carbon can have serious implications on many environmental processes such as soil fertility, erosion and greenhouse gas fluxes.

In response to this issue, the need to understanding and manage SOC stocks in soil is central to several global and pan-European environmental policies. The sweep of UN Conventions arising from the United Nations Conference on Environment and Development at Rio in 1992 (e.g. Climate Change, Biodiversity and to Combat Desertification) all have issue of SOC levels at their core. At a European level, SOC takes a central stage in many policies and strategies of the European Union (EU). The Sixth Environment Action Programme[1] requires the European Commission to prepare a Thematic Strategies on soil. The Communication (COM(2006) 231[1], adopted by the European Commission on 22/09/2006) sets out the overall objective of the Strategy for Soil Protecting 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 (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 revels 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.

The decline of the SOC levels is recognized to be a serious environment threat (COM(2006) 231[1], Huber 2001). Hence, there is an urgent need to develop a common, simple, transparent and cost effective method to identify the changes of organic carbon content in the mineral soil types of the European Union.

In order to meet this challenge, a new method named "Area-Frame Randomised Soil Sampling" (AFRSS) has been developed by the European Commission's Directorate General Joint Research Centre (JRC) in Italy (Stolbovoy et al., 2005). The overall objective of the method is to provide a practical sampling framework that is applicable to agricultural and forest soil. The method is based

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

on a combination of traditional soil survey composite sampling procedures with standardised techniques of randomized geographical positioning of the sampling sites in the field. The method aims to provide: average SOC stock for the single field/forest plot; a unification of the sampling sites positioning; consistency of sampling strategies across the EU; introduction of pedological details into sampling scheme based on the specific nature of the soil profile being sampled; technological simplicity; and cost effectiveness. The method exploits ISO/FDIS 10381-1:2002(E)) and follows ISO 10381-4 “Sampling to support legal or regulatory action”. The innovative AFRSS method is seen as a procedure to supplement the Good Practice Guidance of the International Panel of Climate Change for the project level (IPCC, 2003).

To bring any new method into practice requests considerable validation efforts. This validation exercise is essential to set up boundary conditions for the method and to adopt the method to a practical field survey procedure. For validate the AFRSS, a number of testing plots have been selected in a range of soil conditions across the EU. One of these areas is the Piemonte Region in Northern Italy. There are several reasons to select this study area. Firstly, the Region Administration implements a policy towards the management carbon in soil. Secondly, the region contains a diversity of soil types, which includes a wide range of land uses that are representative of southern Europe. Finally, the region has a well established and effectively operating soil survey organisation, which is open to cooperation and ready to test innovative tools.

The main objectives of this paper are to test the AFRSS method in the field and illustrate the applicability of the method to concrete land cover patterns in Northern Italy. For this purposes the following tasks are considered:

- Background of the AFRSS method
- Adaptation of the method to concrete cropland, pasture and forest plots
- Demonstration of the computation routine
- Analyse of the results of the AFRSS method

Method background

Template description

A randomized sampling template is the core for the AFRSS method. The template represents a grid of 100 cells resulting from a ‘modified random sampling’ with a distance threshold. The numeration of the sampling cells is selected at random with particular care being placed so that no points are less than 6 ‘distance units’ (the grid step) apart. Wherever it is not possible to find points that are separated by more than 6 distant units, the distance threshold is progressively relaxed. This sampling approach prevents a previously sampled cell being too close to the subsequent ones, leading to redundancy in the sampling schema. For example, this can occur both for systematic sampling and 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. But the application of the formulae given in the section ‘uncertainty’ to such sampling plans generally overestimates the variance (Wolter, 1984).

Spatial dimensions of the template differ according to the geographical coordinates of the sampling plot (e.g. field). The template dimensions are defined by selecting the extreme axis X and Y values. The maximum axis value (Maxis) corresponds to the size of the template (Figure 1). The grid size (Gs) is calculated by dividing Maxis by 10 which determines the sampling sites for collecting the composite samples. Following the ISO recommendation (ISO/FDIS 10381-1:2002(E)), the number of sampling points for the composite soil sample is 25. To define the distances between sampling points the Gs has to be split by 5 x 5 grid. The central sampling point within the grid is found by dividing the Gs by 2 and is assumed to be a position of the soil profile. Soil description, bulk density and coarse debris should be taken in this point.

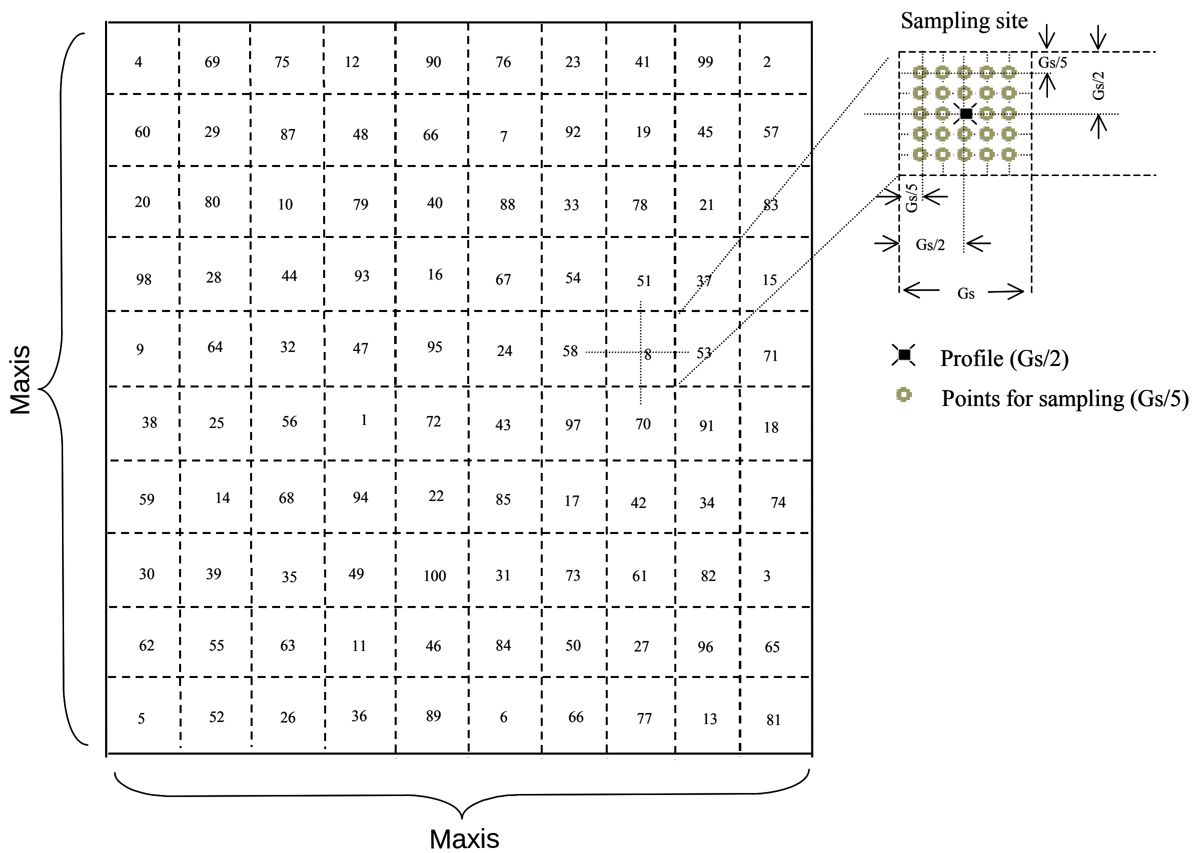

Figure 1. Area-frame randomized template and its parameterization (for explanation see text).

Adaptation of the template[2]

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

- Represent the plot/field margins in coordinates of the standard local projection used for topographic or cadastral maps.
- Define both X and Y Maxis values, as described in previous section and, setup a square accordingly. The coordinates of the corners of this square frame should be preferably “round” figures.
- Overlay on the square the template with 100 points numbered from 1 to 100, as represented in Figure 1.
- Determine the number ‘n’ of sampling sites that is conditioned by the plot area and the need to keep the costs to a minimum (Table 1).
- 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.

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

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

Sampling location

As follows from the adaptation procedure, the plot/field geographical position, location of the sampling sites and soil profiles are presented in the coordinate system. To keep consistency and possible register of the sampled plots/fields at EU level, the geographical positioning should be fixed in European Coordinate Reference Systems (CRS identifier ERTS89 Ellipsoidal CRS) (Boucher, C., Altamini, Z., 1992). The position should be recorded as precise as possible 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.

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

Pedological considerations of the sampling

Because of the global need for the detection of the SOC changes in soil and the necessity for the result compatibility the widely recognized manuals for soil sampling tend to over simplify soil diversity. For example, the IPCC (IPCC, 2003) suggests one standard for all soil types in different land cover classes (e.g., cropland, pasture, forest), which is a column sampling by 10 cm layers of the 0-30cm topsoil. This approach brings serious heterogeneity in the soil parameters resulting in the necessity of increasing number of soil samples to achieve a recommended confidence of the result. The over sampling, as will be shown below, is another disadvantage of the approach in question. To avoid the above mentioned inconveniences the proposed method suggests differentiating soil sampling according to the land cover class and introducing massively composite soil sampling to reduce a laboratory work. This approach allows reducing the sample amount and the cost of the analysis.

Cropland

The cropland-based soil profile can be schematized by two principal horizons: topsoil (the plough layer) and the subsoil underlying it (Figure 2a).[3]

The plough horizon hosts the largest proportion of root biomass and incorporates surface crop residues that contribute to the change in organic content in soils. This horizon is seldom stratified due to regular tillage, physical mixing of soil material throughout, e.g. organic and mineral fertilizers, application of earth, etc., which makes the horizon homogeneous. The thickness of the plough horizon is different depending on conventional cultivation in the country. Therefore, it is proposed that one sample be taken from the middle of the plough horizon for the laboratory analysis that will be representative for the horizon in a whole. For example, if plough horizon is 30 cm thick as illustrated in Figure 2a it is suggested to sample 10-20 cm depth. An undisturbed soil sample to determine the bulk density should also be taken at the same depth.

[3] 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.

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 principal structure and a scheme of soil sampling of pasture are illustrated in Figure 2b, which follows the sampling depth (30 cm topsoil) proposed by the IPPC Good Practice Guidance Manual (IPCC, 2003).

Column sampling of the profile at 10 cm intervals is recommended. These samples will be combined into one composite sample for the laboratory analysis. Undisturbed samples, taken from soil profiles at the three similar sampling depths to determine bulk density should be combined into a composite sample.

Forests

General rules for soil sampling in forests of Europe are specified by the International Co-operative Programme on Assessment and Monitoring of Air Pollution Effects on Forest (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 centres on monitoring of changes in the point and includes details of litter horizon, which are unnecessary when total organic carbon stock is detected.

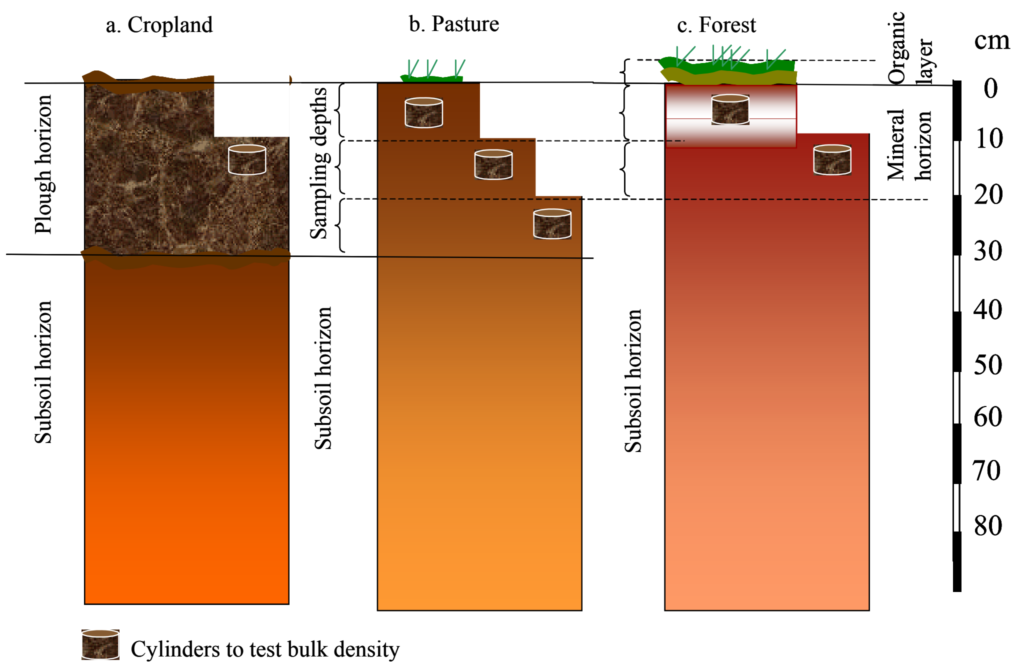

Figure 2. The scheme of soil profile sampling

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 auguring 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.

Algorithms

The changes in organic carbon stock in soils should be measurable, transparent and verifiable, which is in line with some recommendations (IPCC, 2003). These conditions can be achieved if based on physically measured carbon stocks prior to (baseline occasion) and after (second occasion), e.g. the latter can be first or second commitment periods for the Kyoto Protocol (UNFCCC, 1998), etc. Changes derived from models are complimentary and valuable to define potential for carbon sequestration. Area frame randomized soil 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 *per se*.

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 the field 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 field. The computation routine follows steps below:

Step 1: Calculation of soil organic carbon density SCD_{site}[4] for the sampling site:

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

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 field:

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

Where:

SCD_{site} is as indicated in Equation 1

n is a number of sampled sites within the plot

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[4] 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 $\left(\frac{gC}{kg}\right)$.

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

$$SOC_{reference} = S\overline{C}D_p * A_p \qquad (3)$$

Where:

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

A_p is an area of the field

Step 4: Calculation of changes (ΔSOC_{stock}) in organic carbon stock in soils[5]:

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

Where:

$SOC_{refstock}$ is a reference organic carbon stock as indicated in Equation 3

SOC_{new} is a new soil organic carbon stock (second sampling), which is computed similar to $SOC_{reference}$

f_{org} is C applied with organic fertilizers

f_{lim} is C applied with lime

Uncertainty

Uncertainty is a parameter associated with the result of measurement that characterizes the dispersion of the values that could be reasonably attributed to the measured quantity (IPCC, 2003). The uncertainty of the changes in organic carbon stock in soils 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: $\Delta SCD_{site} = SCD_{new} - SCD_{reference}$

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

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

n is a number of sampling sites within the field

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

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

Where:

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

A_p is an area of the field

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 avoiding the normality assumptions.

Reproducibility

The discussed above algorithms arrive at full application of the AFRSS method when time series observations are available. Clearly, the calculation of the changes (ΔSOC_{stock}) in organic carbon stock (Step 4) and the detection of the uncertainty (Steps 5-6) are not possible for the one time sampling.

However, for the experiment we propose to assess the reproducibility (RP) of the sampling method. By the RP we suggest to explore a difference in the averages $S\overline{O}C_{stock}$ resulting from two parallel samplings using the shift in the positioning of the sampling sites. Substantially, this parallel sampling simulates an error of the average $S\overline{O}C_{stock}$ coming from the mistake of the sampling site positioning. It can be suggested that this error appears from a short distance variation of the soil characteristics, which are not tackled by the ARFSS sampling. The variation in question is soil-specific and therefore is a unique for each experimental plot. One can also suggest that this variation is attributed to certain agricultural regions for which soil/land cover combination is common. Technically, the data for RP can be defined as follows. The first sampling is described above. The second sampling sites can be position by applying another GPS device. Because of the accuracy of the latter the shift in positioning will be within few meters. In the case of the lack of the second GPC tool the shift within the mentioned-above limits can be done artificially. The procedure of the second time estimate is similar to that of the first one. Additional computational steps to define the RP will be:

Step 8: Calculation of the difference (absolute) in the averages between first and second estimates of the $S\overline{O}C_{stock}$:

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

Where $S\overline{O}C_{stock1}$ and $S\overline{O}C_{stock2}$ are average SOCstocks for the first and second samplings within given plot

Step 9: Calculation of the reproducibility (RP) of the sampling results for the plot *i*:

$$RP_{plot\,i} = \frac{\Delta SOC_{plot_i}}{S\overline{O}C_{stock1}} * 100 \,,$$

Where $RP_{plot\,i}$ is given in percent

Field validation

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).

Cropland

Cropland plot is situated in the alluvial plain of the Stura river, not far from Turin airport, between Caselle and Leinì towns, an area which was characterised in the recent past by irrigated grasslands for cattle feeding. The expansion of intensive mais cultivation brought to convert this area to arable land, but with higher costs in terms of chemical and mechanical inputs and with higher environmental risks due to contamination of groundwater in a very permeable substratum.

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

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).

The root development is restricted by the presence of highly gravely layers at 45-50 depth. Due to 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.

Soil 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. Gravels and sands constitute the substratum. Ca/Mg ratio is lower due to greenstones and limited soil chemical fertility.

Soil series: *FOGLIZZO coarse-loamy over sandy-skeletal, gravelly.*
Soil Classification:
Soil Taxonomy: *Dystric Eutrudept, coarse-loamy over sandy-skeletal, mixed, nonacid, mesic*
WRB: *Skeletic Cambisol*

Adaptation of the template

The geographic coordinates of the cropland plot margins are given in Table 2. As can be seen, the Xmax is 402175 and Xmin is 401899. By computation (Xmax - Xmin) the difference is 276 m. Applying the same operation to Y coordinates the difference (Ymax – Ymin) is found to be 252 m. The biggest axis value (Maxis) is 276 m and defines the size of the template square (Figure 1). Based on the Maxis value the Gs value would be 276/10=27.6 m. Consequently, the distance between sampling points (Gs/5) is about 5.6 m and the poison of the soil profile (Gs/2) is about 13.8 m in the grid.

Table 2. Geographical coordinates of the cropland plot.

Coordinate axis	x	y
North	**402175**	5004828
South	401278	**5004706**
West	**401899**	5004852
East	402098	**5004958**

Based on the cropland plot area the number 'n' of sampling sites can be defined (Table 1). By calculation it can be found that the area of cropland plot is less than 5 ha. The number of sampling sites should be 3. Following the procedure described in the method section the 1st, 8th and 22nd grids have been selected (Figure 3). The figure provides the coordinates of the soil profiles.

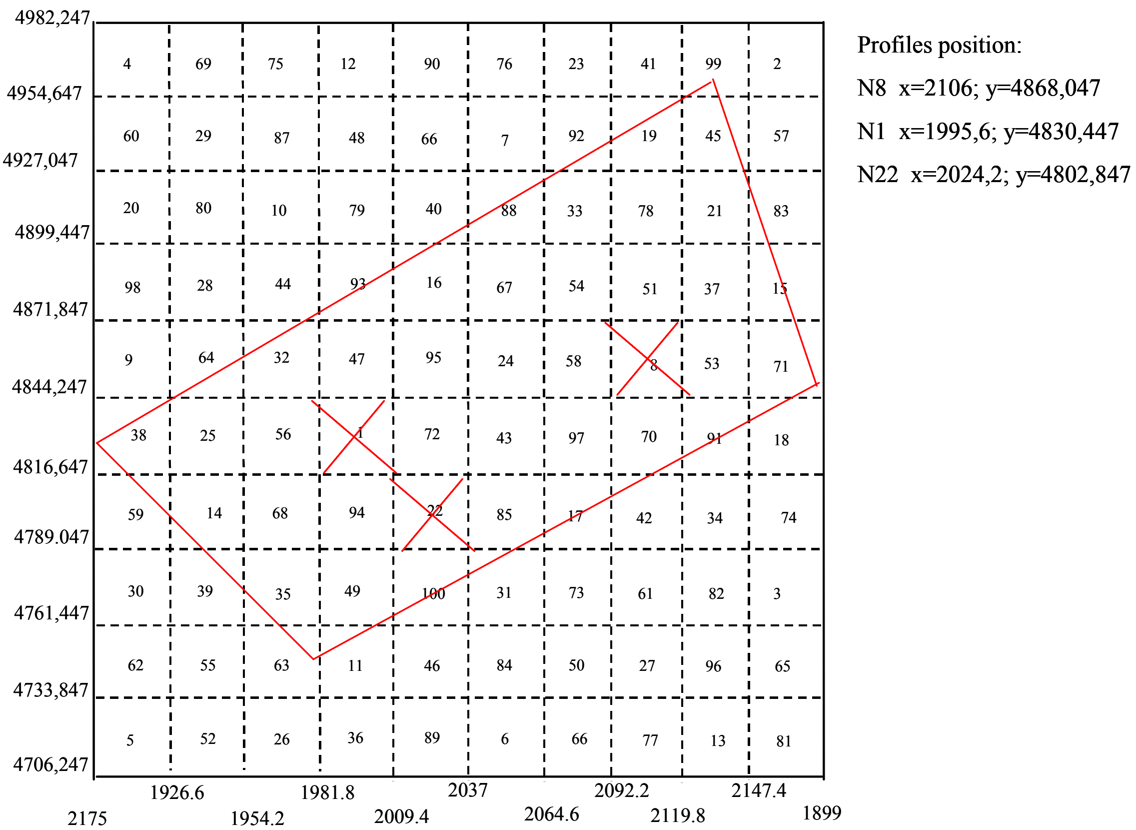

Figure 3. Positioning of the cropland plot on the template and detection of the coordinates of the soil profiles (red crosses).

Pasture

The pasture plot is located in the mountain system of 'Valli di Lanzo' in the western-central Piedmont (Turin province), at the heading of the Tesso valley, a small, north-south oriented, subbasin.

The plot is representative for glacial relief that are completely stabilised at low altitude. Around the glacial circle, occupied by Monastero lake, moraine accumulations, bucked backs and nival valleys are found. The soil profile of the pasture plot is characterised by two horizons: the upper horizon is few centimetres deep. It is rich in organic matter. The bottom horizon is the transitional to the rocky substratum, which is mainly characterised by mixed lithology of greenstones and gneiss.

The shallow depth of the profile is caused by slow rate of soil forming and by young age of the soil formation. These factors are principle limitation of the soils. The pedon is characterised by a high anisotropy due to variability of microrelief 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 series: not attributed
Soil Classification:
Soil Taxonomy: *Lithic Cryorthent, coarse-loamy, mixed, acid, frigid*
WRB: *Dystric Leptosol*

Adaptation of the template

The geographic coordinates of the pasture plot are given in Table 2. As can be seen, the Xmax = 376255 and Xmin = 375917. By computation (Xmax - Xmin) the difference is 338 m. Applying the same calculation to Y coordinates the difference (Ymax – Ymin) is found to be 343 m. The biggest value does correspond to the Maxis and is 343 m, which defines the margins of the template square (Figure 1). Based on the Maxis value the Gs value would be 343/10=34.3 m. Consequently, the distance between sampling points (Gs/5) is about 6.8 m and the poison of the soil profile (Gs/2) is about 17.1 m in the grid.

Table 3. Geographical coordinates of the pasture plot

Coordinate axis	x	y
North	376026	**5025669**
South	376162	**5025326**
West	**375917**	5025521
East	**376255**	5025513

The procedure to identify the number ‘n’ of sampling sites was considered in the cropland section. Similar operation results in the number of sampling sites 3 and respective positioning of the soils profiles are given in Figure 4.

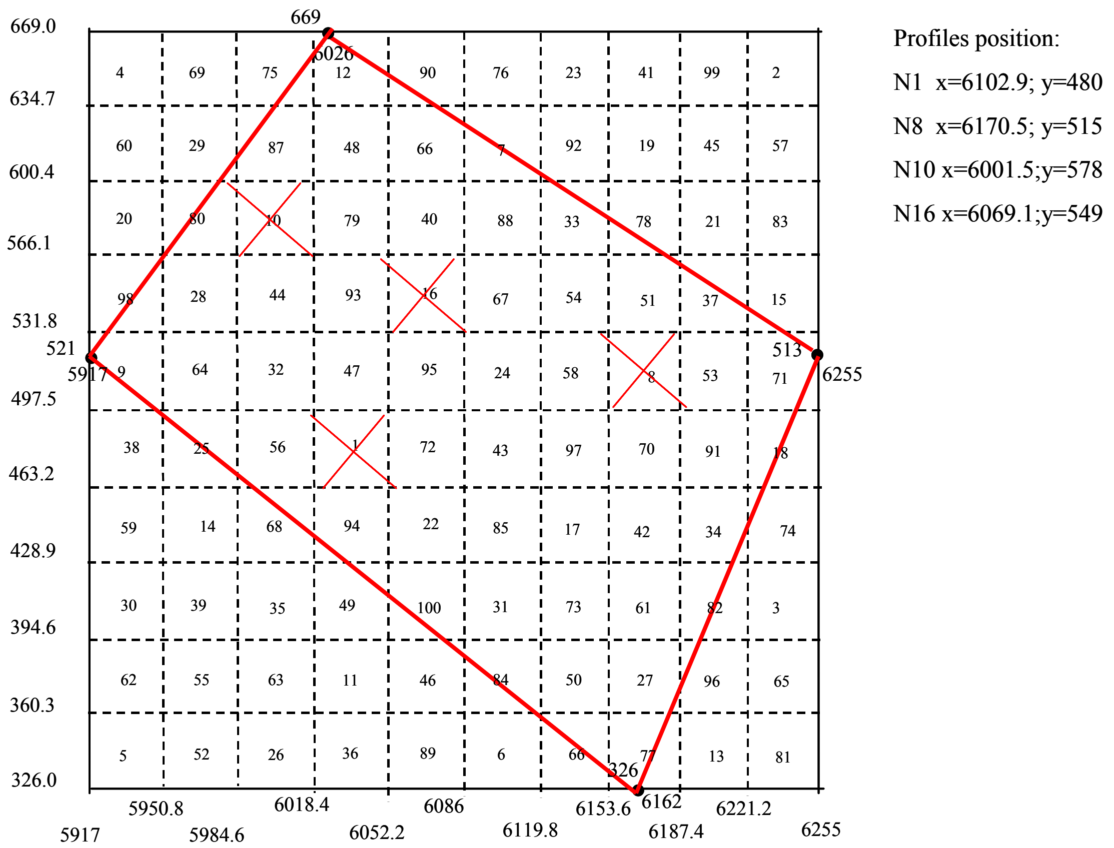

Figure 4. Positioning of the pasture plot on the template and detection of the sampling sites (red crosses).

Forest

Forest plot is situated at 150 m a.s.l., in the lower level of an old terrace, mainly covered by wood (named ‘Partecipanza of Trino’) on the upper part, but used by rice cultivation at the bottom. The terrace is a superstite portion of the ancient plain, suspended on the Po actual alluvial area of around 20 m, in the south of the Vercelli province. The plot is covered by arboriculture of Quercus Robur, started in 1995, on a rice-field.

The plot site in particular is constituted by colluvial eroded soils from the terrace, slipped along the slope to the bottom of the relief, formed on gravely deposits rich in fine sands and in clay, secondly. The original slopes are slightly recognizable due to rice-chambers arrangement. Surface stoniness is very low.

The soil profile of the forest plot soil 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.

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. It has an evidence of clay coats and neutral pH. The C horizon is well recognised below 160 cm. It has colours varied from olive-brown to yellowish-brown with mottles and contains much more gravel that subsoil.

Soil series: *RAMEZZANA fine-silty, typic*

Soil Classification:

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

WRB: *Gleyic Luvisol*

Adaptation of the template

The geographic coordinates of the forest plot are given in Table 4. As can be seen, the Xmax = 441929 and Xmin = 441929. By computation (Xmax - Xmin) the difference is 415 m. Applying the same operation to Y coordinates the difference (Ymax – Ymin) is found to be 131 m. The biggest value (Maxis) is 415 m that defines the margins of the template square (Figure 1). Based on the Maxis the Gs is 415/10=41.5 m. The distance between sampling points (Gs/5) is about 8.3 m and the poison of the soil profile (Gs/2) is about 20.7 m in the grid.

Table 4. Geographical coordinates of the forest plot

Coordinate axis	x	y
North	**441514**	**5006737**
South	**441929**	5006733
West	441917	**5006606**
East	441260	5006678

By calculation it is found that the number of the sampling sites is 3. The position and geographical coordinates are given in Figure 5.

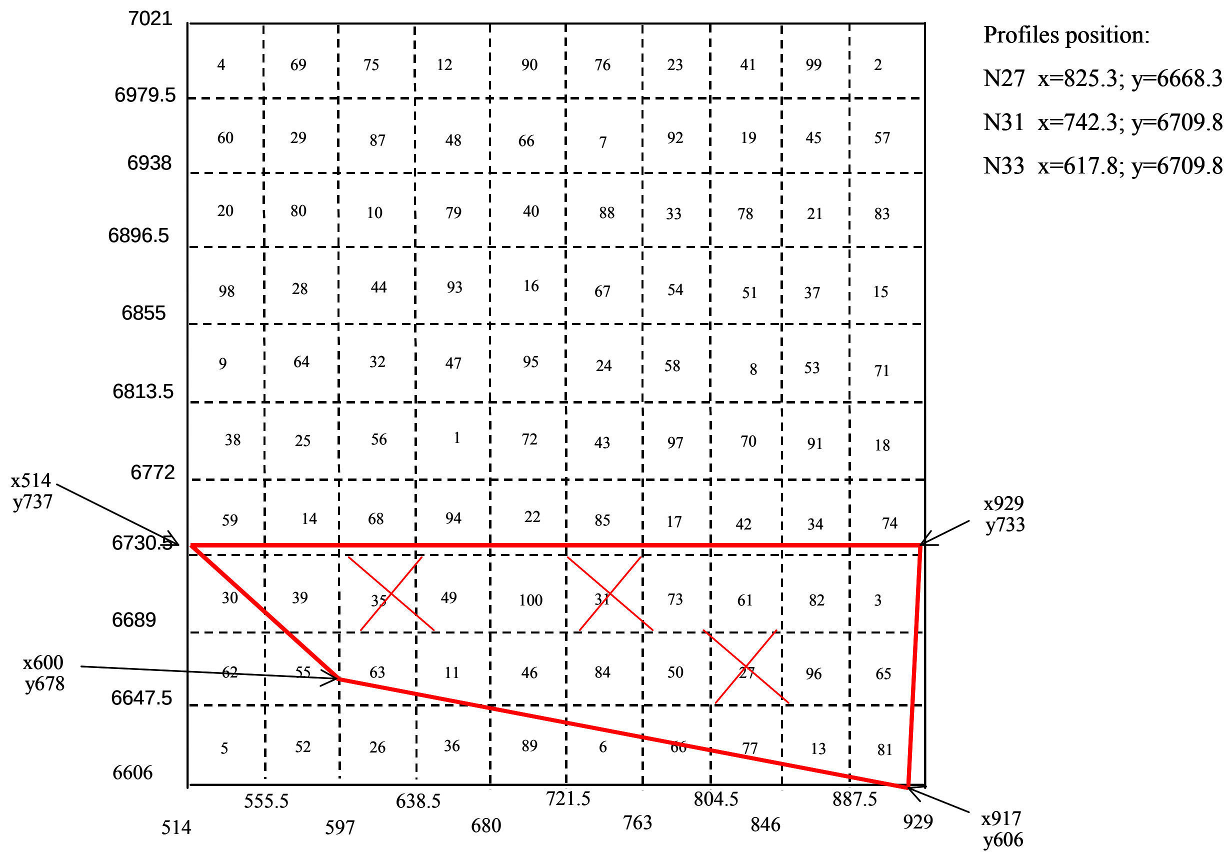

Figure 5. Positioning of the forest plot on the template and detection of the coordinates of the soil profiles (red crosses).

Materials

Field soil sampling provides data on the AFRSS method addressing: (1) calculation of the SCD and SOCstock for the plots; (2) the RP of the measurements related to the plot; (3) effectiveness of the measurements arriving from laboratory cost. Data related items (1) and (2) are presented in Table 5.

As can be seen from the table, the content of C in the cropland *Skeletic Cambisol* varies in the range of 2.0-2.4 %. The range of the C content deviation (0.4%) is relatively low suggesting homogeneity of the cropland soil. We consider the value 1.55% for the profile C8Ss to be too low and exclude it from the analysis. The plough horizon of the cropland soil is rather compacted (the range of bulk density varies between 1.3-1.52 g/cm^3), which is common for low humified *Skeletic Cambisols*. The SCD ranges within 7.0-7.9 kgC/m^2 for the 25 cm ploughed layer. These values might be nearly 15% less if gravel content is accounted. The ignorance of course fraction in the computation of SCD and SOCstock can be accepted because the analysis aims at getting relative and not absolute figures. Two values of the $\overline{SOC}_{stock}$ for the control area (4 ha) of the cropland plot are 301.1 tC (first sampling) and 292.0 tC (second sampling). By calculation it is found that the RP is nearly 3%. This value correspond to the minimum detectable SOCstock change about 9 tC or nearly 2.25 tC/ha for the cropland plot.

The content of C in the pasture *Dystric Leptosol* is much higher than that of cropland soil and varies in the range of 5.6-8.4 % (Table 5). The range of the C content deviation (2.8%) is rather big confirming relatively high heterogeneity of the pasture soil. The 0-20 cm layer of the pasture soil has a considerable variation in the bulk density (0.43-1.37 g/cm^3), which can be explained by the high variability in the amount of roots in the soil. Obviously, the bulk density is low in the samples having abundant roots. The SCD varies widely from 4.1 to 10.2 kgC/m^2 corresponding to the range of the SCD from 95.1 to 181.0 tC/ha for the measured soil profiles. These values should be less if stones content is accounted. The $\overline{SOC}_{stock}$ for the control area of the pasture plot are 516.2 tC (first sampling) and 532.7 tC (second sampling). The RP for the cropland plot is found to be nearly 3%. Expressining this result in the C units gives the minimum detectable SOCstock changes for the cropland plot about 16 tC or nearly 4.0 tC/ha.

The content of C in mineral layer of the forest *Gleyic Luvisol* varies in the range of 1.0-2.0 % (Table 5). The range of the C content deviation (1.0%) is the highest among three sampling plots. The 0-20 cm mineral layer of the forest soil has a high variation in the bulk density (0.95-1.50 g/cm^3), which can be explained by the variability in the root content. The SCD ranges from 0.61 to 2.7 kgC/m^2 for different mineral layers of the forest soil. The average SCD for the total (litter and mineral soil) ranges from 37.8 to 74.1 tC/ha. We consider the value 37.75 tC/ha for the profile F35Ss to be too low and exclude the latter from the analysis. The values of the $\overline{SOC}_{stock}$ for the control area of the forest plot are 196.4 tC (first sampling) and 289.6 tC (second sampling). The RP is found to be rather low nearly 47% what corresponds to the minimum detectable SOCstock change about 92 tC for the forest plot or nearly 23.0 tC/ha.

The tested plots are different in average content and variability of C soils (Table 6). The highest average C content (6.71 %) has *Dystric Leptosol* of the pasture plot. The lowest average C content (1.55%) has mineral horizons of the *Gleyic Luvisol* of forest plot. The average C content in *Skeletic Cambisol* is 2.13 %. Applying the coefficient of variation (*CV*)[6] of the C content as a criterion of the soil homogeneity for the plot we can give good reason to say that cropland soil is relatively homogeneous (*CV* is 9%). The soil of forest oppose is relatively highly variable or low heterogeneous (*CV* is 23%). The soil of pasture shows intermediate feature (*CV* is 15%) among three soils.

Discussion

One of the boundary conditions of the AFRSS method is the degree of the soil heterogeneity at which the method can remain applicable. High variability of carbon content can result in a relatively large value of the minimum detectable SOCstock. For some cases the latter will exceed the amount of the SOCstock changes in soil, which make AFRSS method impractical.

Our field test (Table 5) does not support this hypothesis. In contrast, applying the RP as a criterion of the method sensitivity regarding the minimum detectable amount of SOCstock, the RP value is relatively low in a wide range of soil heterogeneity for the studied plots. For example, the coefficient of variation (*CV*) of carbon content in soil is 9% for cropland *Gleyic Luvisol* and 15% for pasture *Dystric Leptosol* (Table 6). These result in the variation of the SOCstock in the range from 280 tC (C22Ss site) to 314 tC (C1S site) in cropland soil and from 380 tC (PIS site) to 724 tC (P8S site) in the pasture soil (Table 5). In spite of this high variation, as can be seen from table 5, the AFRSS method provides the RP within 3%. Clearly, the result is based on limited field observations and further investigations are needed in order to setup proper boundary conditions of the AFRSS method regarding soil heterogeneity in agricultural fields.

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[6] It is calculated by equation: $CV = \frac{\sigma}{\mu} * 100$, were σ is the standard deviation and μ is the mean.

Table 5. Soil characteristics of the sampling plots (for computation routine see section on algorithms).

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	3
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								
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.a	n.a		
Pasture *Dystric Leptosol*, first sampling								
P8S	0-10	7.38	1.07	7.90	181.0	723.8	516.2	3
	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	380.28		
	10-20	5.75	0.72	4.14				
Pasture *Dystric Leptosol,* second sampling								
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				
Forest *Gleyic Luvisol,* first sampling								
	Litter			n.d.**			196.4	47
F27S	0-10	2.04	1.33	2.71	50.68	202.7		
	10-20	1.57	1.50	2.36				
	Litter			11.49				
F31S	0-10	1.92	1.15	2.21	47.51	190.4		
	10-20	1.01	1.38	1.39				
	Litter			0.61				
F35S	0-10	1.56	1.23	1.92	37.75	151.0		
	10-20	1.36	1.32	1.80				
Forest *Gleyic Luvisol*, second sampling								
	Litter			3.69			289.6	
F27Ss	0-10	1.43	0.95	1.36	74.1	296.4		
	10-20	1.57	1.50	2.36				
	Litter			3.28				
F31Ss	0-10	2.1	1.12	2.35	70.2	280.8		
	10-20	1.01	1.38	1.39				
	Litter			3.63				
F35Ss	0-10	1.87	1.11	2.08	72.9	291.6		
	10-20	1.26	1.25	1.58				

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

Table 6. Average and coefficient of variation in carbon content in the tested plots.

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

The data obtained from the forest plot are different from that of agricultural fields. The observed characteristics of the forest *Gleyic Luvisol* are relatively variable (*CV* = 23%, table 6). The high heterogeneity of the $S\overline{O}C_{stock}$ for the forest plot is found for SOCstock, (e.g. 190 tC (site F31S) and 296 C (site F27Ss)). As a result, the parallel soil sampling yields PR of about 47% in the forest plot This value appears to be an error. The very high RP originates from unsatisfactory data quality on the forest *Gleyic Luvisol*. The most serious doubt comes from unclear nature of the systematic difference in the SOCstock in the course of the second sampling (Table 5). The difference between first and second time samplings is really high, e.g., 196.4 tC (first sampling) and 289.6 tC (second sampling). This observation seriously questions the accuracy of the both sampling experiments. Another observation is that some measurements in forest soil are incomplete, e.g., the profile F27S does not contain data on the litter. Based on these observations, the experiment in the forest plot should be repeated.

There is common opinion that confidence limits about estimates of the SOCstock are large (e.g. see Batjes, 1996), which is an argument against the implementation of the soil for the LULUCF accounts. It can be thought if the uncertainty of the SOCstock detection is large at the first time sampling the verification of the SOCstock changes at the second time sampling will be even more biased and less confident. For instance, the second sampling will assimilate both the errors of the first and second time samplings. However, this assumption is based on general considerations and has to be checked against field measurements. Data from the Piemonte Region clearly illustrate the uncertainty of C detection in soil. Especially, on how deviation of the $S\overline{O}C_{stock}$ depends on the value of the SOCstock. With certain reservations the analysis illustrates the uncertainty of the SOCstock detection (measured by deviation of the SOCstock average) for the soil approaching SOCstock saturation. To perform the analysis in question the plot of $S\overline{O}C_{stock}$ in the order of the increasing values for each tested plots and observe the average deviation of the latter (Figure 6).

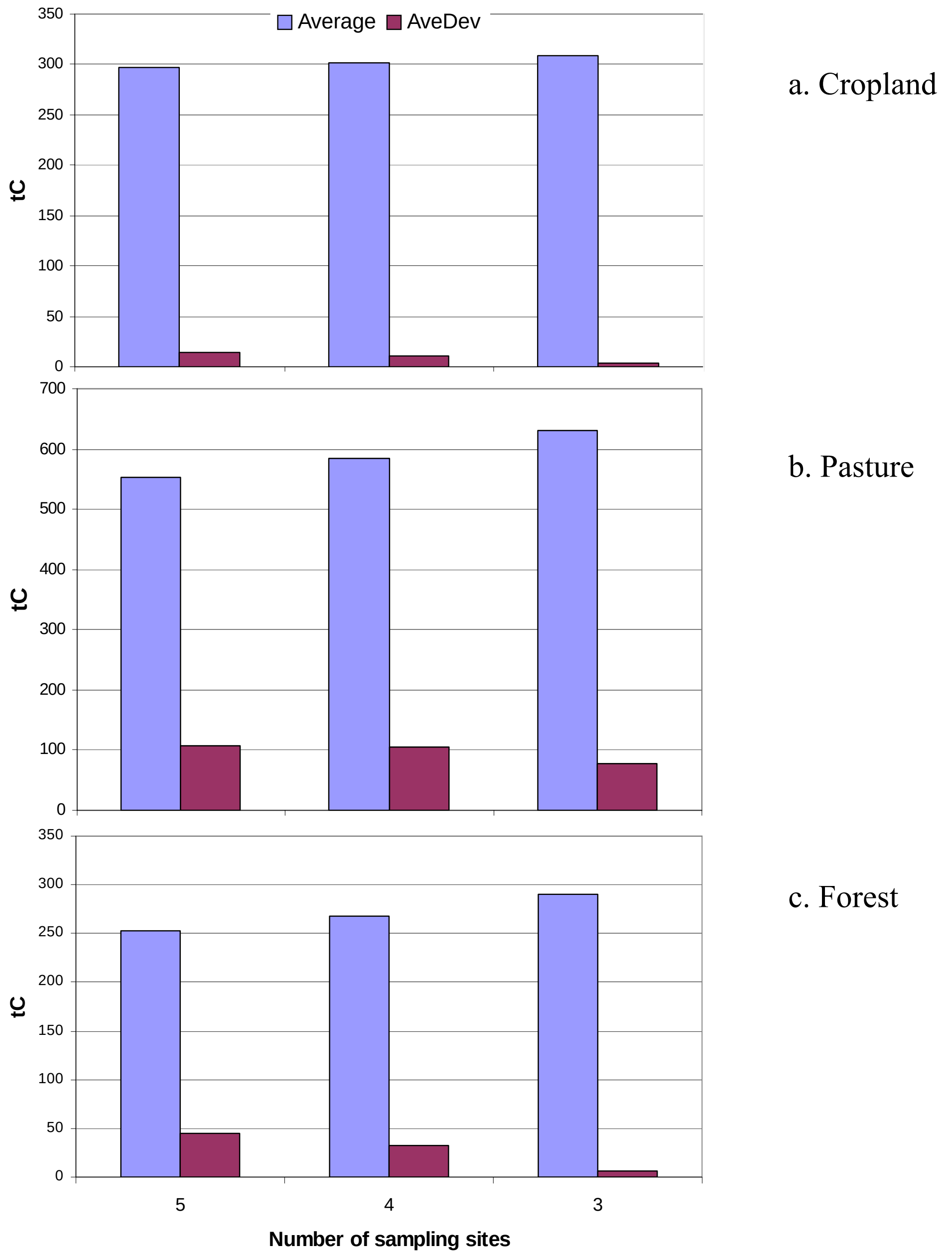

Figure 6. Carbon stock ($S\overline{O}C_{stock}$) in tC and average deviation (AveDev) for: a) Cropland, b) Pasture and c) Forest plots. The thicknesses of the layers are: ploughed horizon = 25 cm, pasture topsoil = 30 cm; forest soil litter plus 20 cm mineral topsoil. Control area of the plot is 4 ha.

As can be seen from figure 6, the $S\overline{O}C_{stock}$ values and their average deviation is different for different plots depending on variation of soils between the tested plots (e.g. *Skeletic Cambisol* (cropland), *Dystric Leptosol* (pasture) and *Gleyic Luvisol* (forest)). The difference in soil characteristics are clearly observed in table 5 (see also Annex 1).

The variability in the SOCstock in cultivated *Skeletic Cambisol* (Figure 6a) is lower because of the selection of the relatively homogeneous soils for cropping.

The deviation of the $S\overline{O}C_{stock}$ is less for the case of the higher carbon content in the cropland. Similar low deviation for the richer carbon soils is observed for the pasture and forest (Figure 6b and 6c). However, the latter soils show relatively higher variation of the $S\overline{O}C_{stock}$. This high variation is caused by the initial heterogeneity in soil, which is common for these land use types. Figure 6 shows that all tested soil types illustrate a common pattern of the dependence between $S\overline{O}C_{stock}$ and their deviation (e.g., the smallest average deviation is found for the highest $S\overline{O}C_{stock}$). This finding suggests that the uncertainty of SOCstock verification expects to be less where the soil approaches SOCstock saturation. The application of C sequestration practices and enriching soil with C leads to the narrowing of C standard deviation values and the uncertainty of the detection of the changes in the SOCstock will decline. This demonstrates that strategies to utilize the soil compartment for carbon sequestration practices are justified.

Economic effectiveness

Laboratory costs

The cost of any soil sampling programme consists of different components which include the number of samples collected and the laboratory cost of the carbon determination. Requirements for the conventional point sampling procedure recommended by IPCC (IPCC, 2003) will be compared with the AFRSS methodology. The IPCC procedure recommends that nine soil points are tested, each containing three sampled depths (0-10, 10-20 and 20-30 cm). These samples are required to study the spatial variability of the soil parameters for the first time sampling. On the basis of these data, the number of the soil samples needed for the second time sampling is estimated. IPCC propose to detect the changes in the SOCstock with a confidence level of 95%. The CV of SOC content in the soil of the experimental plots is given in Table 6. In the three field measurements in cropland, pasture and forest this variability turned out to be 9%, 15% and 23% respectively.

If value $CV(SOC) = 0.09$ is taken as an example, then:

$$s\left(S\overline{O}C\right) = 0.09 \times SOC$$

Our target is to estimate the SOC with a confidence semi-interval of 1.5 tC/ha (suggested average annual C accumulation in soil) with a 95% confidence level. We assume that this amount corresponds to approx 2% of the SOC, i.e. that the SOC is around 75 tC/ha. To achieve this, the coefficient of variation of the estimate is required to be:

$$CV\left(S\overline{O}C\right) = \frac{s\left(S\overline{O}C\right)}{S\overline{O}C} = \frac{0.02}{t_{95}} \quad \Rightarrow \quad s\left(S\overline{O}C\right) = \frac{0.02 \times S\overline{O}C}{t_{95}},$$

where $t_{95} = 1.96$ if the sample size is large enough but can be above 2 for a moderate sample size, specially if the distribution of SOC is not Gaussian. If the approximation $t_{95} \approx 2$. For a lower confidence level we would have $t_{65} \approx 1$ or $t_{90} \approx 1.7$ if we assume that the distribution of SOC is normal.

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

$$s\left(S\overline{O}C\right) = \frac{s(SOC)}{\sqrt{n}}$$

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

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

Where t_{95} must be substituted by t_{conf} for a different confidence level and 0.02 by "z" if the targeted precision is z% of the SOC. Applying similar consideration the number of samples needed is 225 for pasture and 529 for forest plots.

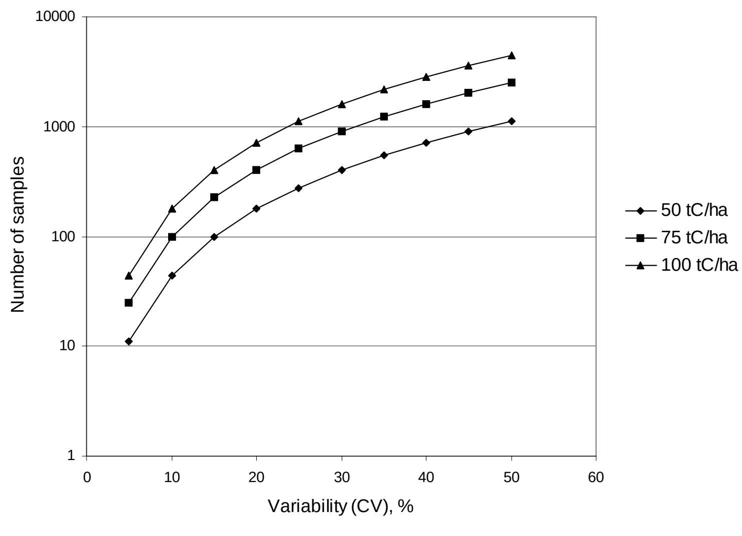

Figure 7. Number of samples for simple random sampling for the minimum detectable changes of 1.5 tC/ha with 95% confidence depending on the SOC variability and the average SOC in the field.

Figure 7 illustrates the considerations in general form for the average soil conditions of Europe. For example, the SOC density varies from 50 to 100 tC/ha and average sequestration of carbon in soil is 1.5 tC/ha. The figure shows that the number of the samples is rather large even for relatively homogeneous soil (e.g. CV below 10%). This number 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 sites in total for cropland, 675 samples for pasture and 1587 samples for forest (Table 7).

Multiplying the number of samples by the range of the costs for determination of carbon in laboratory from €6 to €16 per one analysis, where the lowest price (€6.00) is taken from CARBOEUROPE project (see www.carboeurope.org) and highest price (€16.00) is indicated by BIOSOIL project (see http://inforest.jrc.it/activities/ForestFocus/biosoil.html), calculates the total cost of the laboratory treatment. If the plot area is about 4 ha, the amount of accumulated carbon is assumed to be 6 tC, then the cost of the analysis for one tonne of accumulated carbon will range from €241 to €643 tC for cropland, from €675 to €1800 tC and from €1587 to €4332 tC. Clearly, these high costs make the routine measurement of C sequestration rates in soil impractical.

Table 7. The laboratory costs of C detection under conditions: the average C sequestration is 6tC for the control (4ha) plot; the laboratory price of the C detection is in the range €6-16 for 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

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 4 ha area (see Table 1). The cost of the analysis will range from €3 to €8 tC depending on the above mentioned laboratory prices. The detection of the carbon in the forest plot requests analysis of six samples for 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 7 shows that the analysis cost provided by AFRSS is practically feasible, especially, if the these costs are recalculated to tCO_2_eqv. For this computation, the costs in Table 7 are subdivided by factor of 3.67, which is a 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 pasture.

Effect of the plot area on laboratory cost

Figure 8 provides a tentative cost of the carbon determination in the laboratory depending on the area of the plot. As can be seen from the figure, the laboratory cost decreases with the increase of the size of the sampling plot: e.g., the cost to detect 1 tC in the field having 1 ha is nearly 35 Euro. This cost will be about 0.13 Euro if the cropland field is some 50 ha.

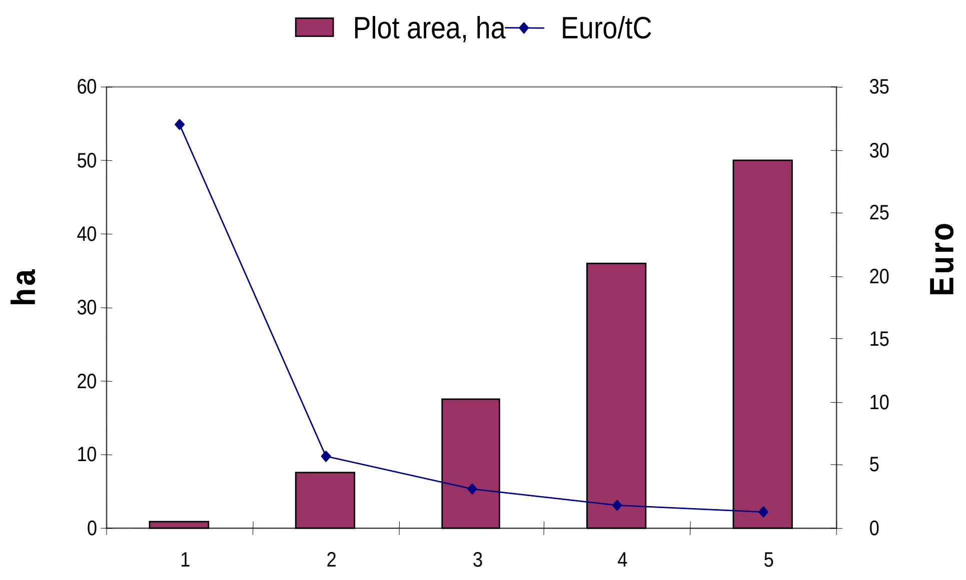

Figure 8. Dependence of the laboratory determination of C on the cropland area. Conditions: average carbon sink in agricultural soils is 1.5 tC/ha; the cost of carbon determination in laboratory is 16 Euro.

Conclusions

The new method, AFRSS, has been developed to detect the changes of organic carbon stock in mineral soils. The field-testing of this method has shown the following general advantages:

- technical simplicity;
- instrumental (GPS) positioning of the sampling sites;
- uniform design of the sampling strategy ensuring project's consistency;
- pedological details are retained by the sampling scheme;
- cost effectiveness.

The test of the AFRSS method in the field shows high RP of the C detection in a wide range of soil heterogeneity (e.g. the RP of the method was nearly 3% in the plots having a variability of soil parameters within 9-15% in cropland and pasture).

For all tested soil types (e.g. *Skeletic Cambisol* (cropland), *Dystric Leptosol* (pasture) and *Gleyic Luvisol* (forest)), the deviation of the $S\overline{O}C_{stock}$ becomes less for the higher $S\overline{O}C_{stock}$. This shows that the uncertainty of the C sequestration measures will decline in the course of the C enrichment in the soil. This finding supports the development of policies based on the assumption for the use of the soil compartment for greenhouse mitigation policy.

The AFRSS method shows a high cost-efficiency. The laboratory cost in one tC varies from 3 to 8 EURO for cropland and pasture soils and from 6 to 16 EURO for forest soil. The cost of the analysis is very small if the size of the sampled field is large enough. For example, in the case of the cropland field of around 50 ha, the cost of the analysis in one tC is nearly €0.13. This brings the economic cost of the detection of the changes of the organic carbon stock in mineral soils to the practical level.

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Annex 1 Description and laboratory data on soil

Cropland plot

Geographic distribution and pedolandscape

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

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

Soil properties: soil is characterised by a loamy or silty-loam texture and by a low macroporosity due to iron oxides (mottling and concretions). Consequently drainage is moderate as well as oxygen availability.

Main feature is the root restricting depth at 45-50 cm, due to highly gravelly layers. Oxigen availability is good, drainage is moderately high and saturated hydraulic conductivity moderately high, as they are 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 by 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 s.l.m.

Soil use: rotated wheat

Lithology: serpentine

Morphology: alluvial plain

Photo: the soil profile LIQU0050, characterised by sandy-loam texture
with evident presence of pebbles from alluvial gravel deposits of Stura river

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: incoherent; 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 incoherent; 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 plot

Geographic distribution and pedolandscape

The heading of the Tesso valley, where this site is located, is a good example of slope and ridge morphologies over glacial morphologies which are completely stabilised at low altitude. Around the glacial circle, occupied by Monastero lake, is therefore possible to recognise sloping and ridge morphologies, moraine accumulations, bucked backs and nival valleys.

Soil series

Not defined

Soil properties

The studied site is characterised by alternance of deeper soils with an A-AB-Bw-BC-C layers sequence and shallow soils characterised by the presence of only two layers: the first is few centimetres deep and in rich in organic matter, the second is the interface with the rocky substratum. The pedon is characterised by a high anisotropy due to variability of microrelief 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, Monastero Lake, Lake Alp, Chiaves

Profile classification:

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

WRB: *Dystric Leptosol*

Slope: 30°

Exposition: 270°

Elevation: 230 m s.l.m.

Soil use: alpine pasture

Lithology: serpentine

Morphology: slope with rocky leaps

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

Photo: profile LANZ0069 in the maximum depth

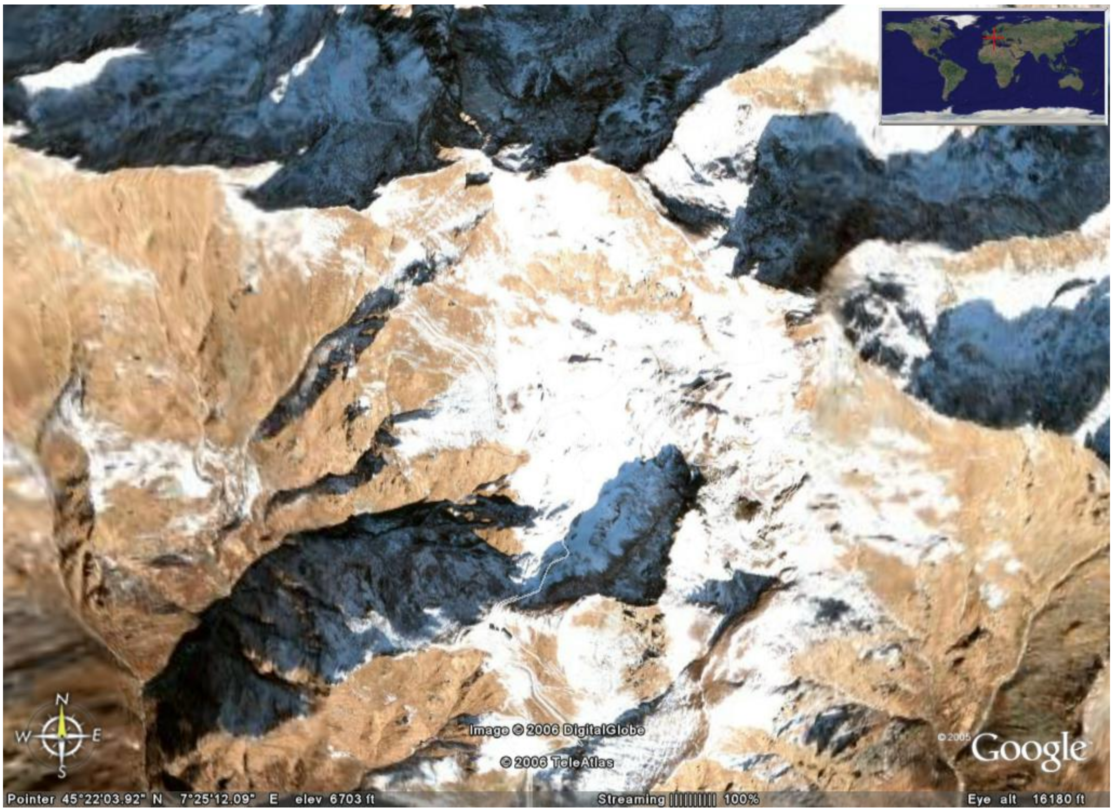


Photo: satellite image of the mountain site morphology

Forest plot

Geographic distribution and pedolandscape
The more diffused soil type is a Luvisol (WRB), which covers the lower level of the old terrace in the Partecipanza of Trino (Vercelli province). Wavy 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 placed at 150 m a.s.l., 20 m higher than the main plain. The original slopes are slightly recognizable due to rice-chambers arrangement. Surface stoniness is very low. Land use is rice-growing.

Soil series: RAMEZZANA fine-silty, typic

Soil properties: soil is characterised by a loamy or silty-loam texture and by a low macroporosity due to iron oxides (mottling and concretions). Consequently drainage is moderate as well as oxygen availability. 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.

Profile: it 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 sediments

Morphology: lower part of ancient terrace

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

Photo: the arboricolture 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), colour type: reducted; loamy;; non gravelly, clod structure, few macropores (less than 1 mm medium size), no roots, rooting 90%, consistence: moderately resistent; 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 gravelly; 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	-	-	-

Allegato B

AFRSS_Template.avx

Build a template with Area-Frame Randomised Soil Sampling (AFRSS) method

http://arcscripts.esri.com/details.asp?dbid=14781

About

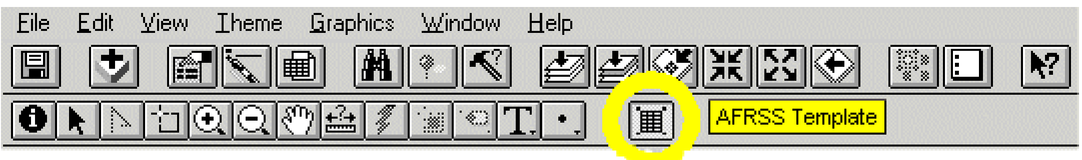
AFRSS_Template extension was developed to automate the process of building a template over agricultural and forestal plots according with a new method of soil sampling named "Area-Frame Randomised Soil Sampling" (AFRSS) (Stolbovoy et al. 2005) . The Kyoto Protocol (UNFCCC, 1998) considers soils as an essential component to mitigate the increasing concentrations of greenhouse gases in the atmosphere. The objective of the AFRSS is to design a protocol for soil sampling at the Land Use, Land-Use Change, and Forestry (LULUCF) (IPCC, 2000) 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.

Installation

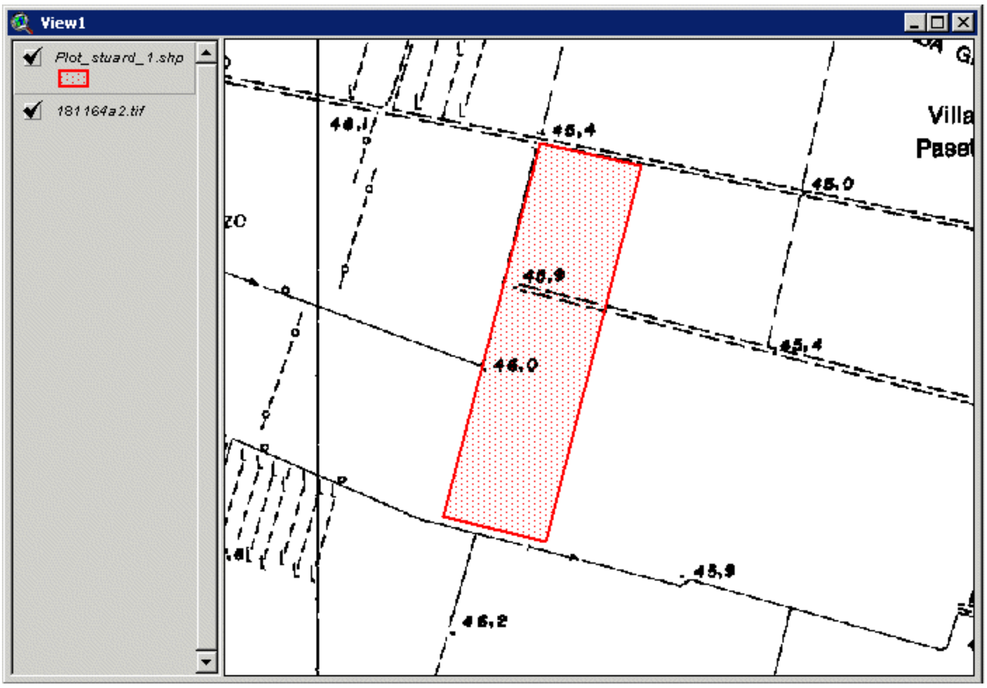
If the ArcView GIS software was installed using the standard defaults, the extension should be placed in your "C:\ESRI\AV_GIS30\ARCVIEW\EXT32" directory. If the user organization has explicitly set a new pathname for the $USEREXT system variable, the avx file should be placed in the corresponding directory.

Getting Started

To use the extension, you must first load it into current ArcView project. This is done from the "Extensions" dialog box accessed through the "File" pulldown menu. Look for AFRSS_Template in the list of "Available Extensions" and place a check in the box next to the title. This will load the AFRSS_Template Extension into ArcView. When you open a view you will see the AFRSS_Template tool.



AFRSS_Template tool



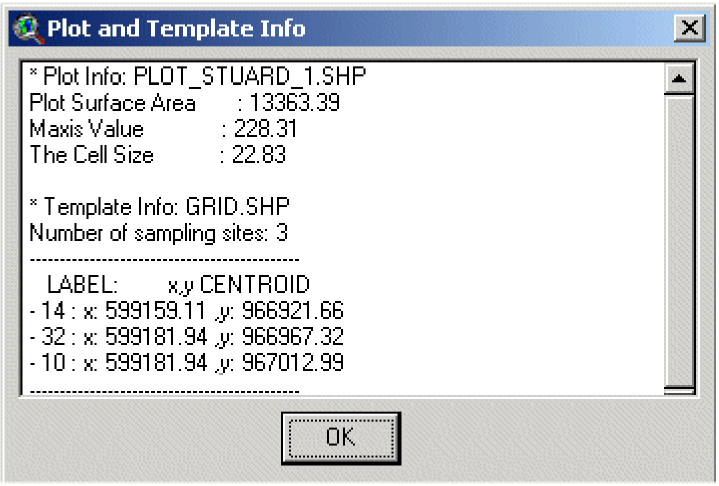
Lets you select a polygon feature from the active theme in the view. Before you use this tool, make the theme from which you wish to select

features active, by clicking on its name in the view's Table of Contents. If this tool remains dimmed out after you make a theme active, that theme does not contain polygon features. You select features by clicking on them individually. Features that you select are highlighted on the view. After that, if the shape area is greater than or equal to 5000 square meters, you will prompted to provide a name and location for the new Template shapefile.

The tool would then generate a Template based on polygon geometric shape. When the building process is completed the shapefile will be added to your view as new theme and a message box about selected polygon and Template will be displayed.

Plot and Template Info

As show in the image, the info box supply some informations about main parameters used to build the template and the number of sampling sites conditioned by the plot area.



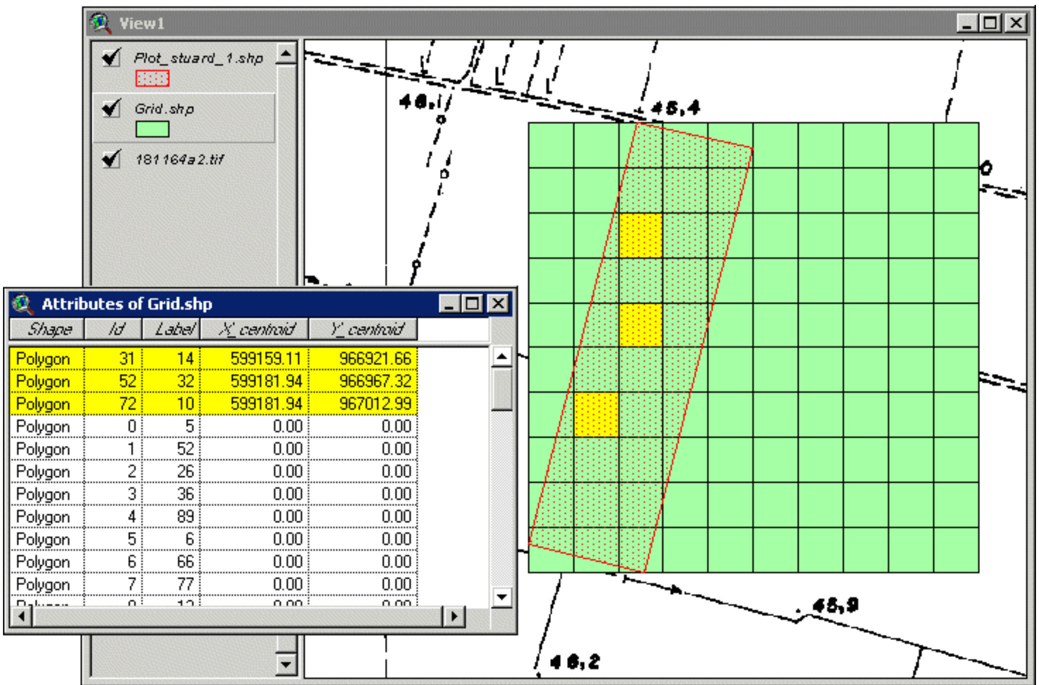
These information were copied to the system clipboard. Open a text editor like Notepad, paste the contents of the clipboard, and save or print them from the text editor.

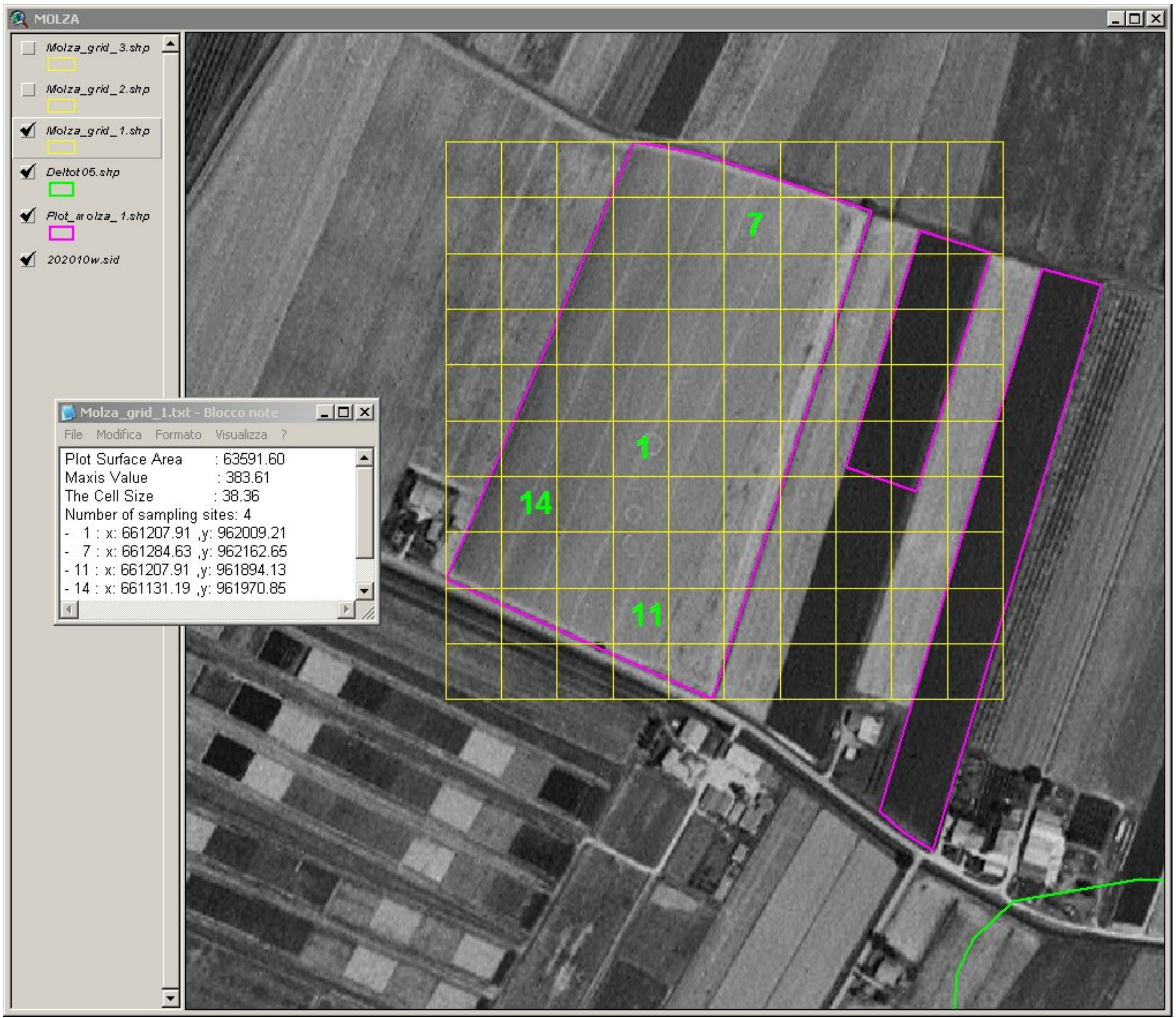
Template

The sampling sites are selected and identified on the the Attributes Table of the Template with the LABEL field. For each selected records the Extension returns the centroid calculation, fields X_CENTROID and Y_CENTROID, to the selected set of records.

Support

Let us know what we can do to improve the tool and make it work even better for you. Currently, technical support for AFRSS_Template.avx is available through email to rbertozzi@regione.emilia-romagna.it





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