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# Strength and weaknesses of a bottom up approach in estimating soil organic carbon: an experience in the varied Italian scenery

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## Abstract

A first attempt to provide consistent information about soil organic carbon stock in Italy was made through a pilot project set up by the National Institute for Environmental Protection and Research in Italy (ISPRA), involving regional soil services. Aim of the project was the exploitation of the most updated and detailed available information, through local expertise, in order to give reliable answers to the urgent need of information on soil, at national and European level, providing an harmonized and shared tool, according to the bottom-up approach. The common infrastructure for data sharing, consisted of a 1 $km^2$ reference grid and an exchange format for storing data and metadata, simplifying harmonization and up-scaling issues, easy to query and update, ensuring consistency with European standards and procedures. Main issues in SOC assessments were bulk density evaluation, comparability of analytical methods and of different spatial distribution modelling.

*Keywords: soil organic carbon assessment, soil bulk density, harmonization*

## Introduction, scope and main objectives

Since soil is a non-renewable resource increasingly under pressure, there is an urgent need for consistent and reliable information. Since the comparability of information on soils is limited, often based on few data, collected using different methodologies (Sulaeman *et al.*, 2013), the Institute for Environmental Protection and Research has financed and started the SIAS project to develop a new approach that exploits the more updated and detailed information on soil and the expertise available at local level to build reliable indicators on some soil threats at national level. This pilot project has been focused on soil erosion and loss of organic matter, as these were two of the main threats identified by the European Commission in the Thematic Strategy for Soil Protection and Proposal for a Framework Directive (COM 2006, 231 and 232; European Commission, 2006). Partners of the project were 16 Regional Soil Survey Services out of 20 regions, that contributed defining methodology, elaborating soil data and assessing soil indicators for their own region, under the technical coordination of the Environmental Protection Agency of the Veneto Region. Other partners were CRA-RPS (Research Centre for the study of plant-soil relationship), and the Land Management and Natural Hazards Unit of JRC, for implementing the methodology of up-scaling data, ensuring consistency with European standards and procedures.

## Methodology

Every Regional Soil Survey Service has been asked to participate in defining an exchange format at first, and later in filling the format in, concerning the soil indicators and all related information (metadata).
To overcome harmonization problems, it has been decided to assess and present output data on a reference grid, with a common coordinate reference system, setting up a common infrastructure for data sharing. The reference grid has been built following the recommendations of the INSPIRE Directive (European Parliament, 2007). For SIAS project, a 1 km grid was chosen, seeming a good compromise between information quality, operability and goals of the project.
To collect pixel data and meta-information, an exchange format was set up jointly by the working group; the format was then developed as a database. Information about soil organic carbon stock was stored as well as

some data quality indicators, shared by the working group, both as quantitative indexes of data availability in the pixel and as specific confidence levels in each pixel.
Special emphasis of the project lays on exploitation of local expert judgement ("bottom-up" approach) so that local experts can follow the most adequate assessment procedures up to their judgement, as long as procedure paths were recorded into metadata, that was the project value-added information.

Organic carbon stock (t ha-1) has been calculated for 0-30 cm, 0-100 cm and for holorganic layers, through the following formula, applied for each profile or Soil Typological Unit (STU):

$$O.C. = \sum_{1}^{n} o.c. * b.d. * depth * \frac{(100 - sk)}{100}$$

where:
O.C.= profile/STU organic carbon content (t $ha^{-1}$);
o.c.= horizon organic carbon content (%);
b.d.= fine earth bulk density of the horizon (g $cm^{-3}$);
depth = horizon depth (cm) within the given section;
sk = horizon rock fragment content (%);
n = number of horizons within the given section.

In order to have a comparable assessment, organic carbon data obtained by means of local analytical methods have been converted into ISO method results, according to specific regression functions. These were developed thanks to results of a ring test worked out among several public Italian laboratory for soil analysis. Concerning bulk density, both measured data and pedotransfer function (PTF) were used; some regions used original PTFs calibrated on own measured dataset (Ungaro *et al.*, 2005a), the other ones used literature PTFs.

To assess organic carbon content within the pixel, different pathways have been followed, as every Regional Soil Service could choose the most suitable one for its specific situation:

- by means of a soil map, calculating the weighted average of STUs in the SMU (soil mapping unit), or the average of single profiles in the SMU;
- using geostatistical analysis, usually by means of kriging with varying local means calibrated on SMUs (Ungaro *et al.*, 2005b; Deutsch and Journel, 1998; Goovaerts, 2001).

As final step, organic carbon stock within the pixel has been intersected with a land-cover map, Corine Land Cover or more detailed regional map, to obtain the final value of t ha-1, subtracting no-soil surfaces.
All information (analytical-measurement methods, PTFs and regressions used, data time span, spatialization and up-scaling methods, land-cover scale and year) has been recorded in the metadata section of the exchange format.

## Results

The project started in 2008 but not all regions could take part, as some lack a regional soil service.
Organic carbon stocks for 0-30 cm for 17 regions out of 20 are shown in figure 1. The approaches used for organic carbon stock evaluation were different in different regions, sometimes even in different areas of the same region. In areas where a soil map was available, carbon stock could be calculated by means of weighted average of STUs in the SMU or as average value of observations within the SMU.
Where more detailed maps were available, observation density higher and local expertise adequate geostatistical analysis could be applied for data spatialization (kriging with varying local means calibrated on functional groups of STUs), requiring data such as single observation organic carbon percentages, measured bulk density (where available) or estimated bulk density calculated by means of pedotransfer-functions (e.g. in Veneto and Emilia Romagna alluvial plain).
Graphs in figure 2 shows mean carbon stocks of 10 out of 20 regions. Average SOC in plain areas goes from 34 to 60 t $ha^{-1}$ in the 0-30 cm section, with the lowest values in southern Italy (34 t $ha^{-1}$) and the highest (51-

60 t ha$^{-1}$) in the north (Po plain). Average SOC in the 0-100 cm section ranges from 78 to 154 t ha$^{-1}$ in the plain, with the same geographical trend. In the Alps SOC is quite variable, going from 59 to 103 t ha$^{-1}$, on average, for the 0-30cm section, and from 87 to 160 t ha$^{-1}$, for the 0-100cm. Central and southern mountain areas (Appennini) have average contents of 50-58 t ha$^{-1}$ within 30 cm and 95-114 t ha$^{-1}$ within 100 cm.

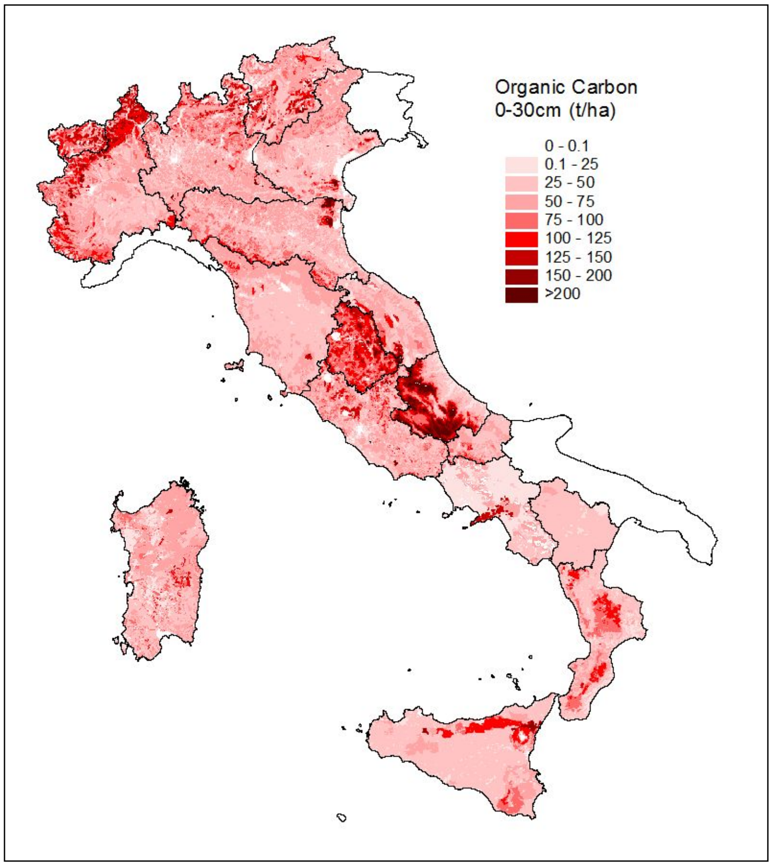


**Fig. 1: 0-30 cm SOC (t ha$^{-1}$) in 17 regions out of 20.**

## Discussion

Different problems were faced during the project. In the beginning, partner involvement has not been easy, since interest and various region know-how was quite different. Bulk density assessment turned out to be a weakness point, since different PTFs often give very different results, strongly depending on the environment where they have been developed and calibrated. Several regions had large datasets of measured bulk densities, that were used to develop local PTFs, that turned to be useful also to other regions with similar environments. Once the common infrastructure has been shared and accepted, all regions had to face different technical problems. Know-how seemed to vary a lot among regions, so that a main group of more expert regions acted as technical guide for other, less experienced, regions.

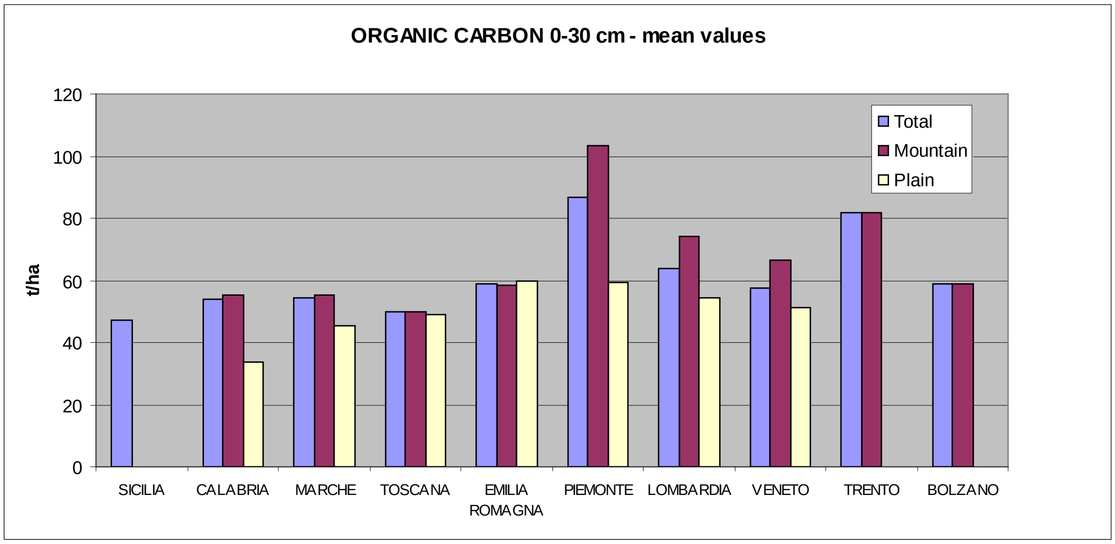


**Fig. 2: Mean 0-30cm SOC values in the most representative regions (t $ha^{-1}$).**

## Conclusions

At the end outputs of 17 out of 20 regions were available, giving not a complete picture, but far enough to face main correlation and harmonization issues. Bulk density PTFs, locally developed or available in literature, together with comparability of different methods of soil laboratory analysis and different methods of data spatialization were the main issues. 1 km pixels seemed to be a suited tool for representing SOC indicator.

SIAS project was the first Italian attempt to provide consistent information about soil organic carbon stock. It has also provided, according to the bottom-up approach, an harmonized assessment tool for exploitation of local expertise, that can guarantee the use of the most up to date information and the more reliable assessment, and can be used to work out a national shared result, coherent with European and international standards. The project suffered from an insufficient financing and from the varied Italian scenery, where regional soil survey services are entrusted to the good will of the individual regions, lacking a regulatory framework at national level.

Within a second phase of the project with a major investment, a further step should be to face harmonization problems, i.e. gain a better comparability of results and smoothen differences due to diverse assessment methodologies.

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