# Development of a bottom-up approach for soil indicators: organic carbon and soil loss assessment for the Italian territory

**Author Block:** I. Vinci[1], F. Fumanti[2], P. Giandon[1], S. Obber[1], P. Panagos[3];
[1]Regional Soil Observatory ARPAV, Castelfranco Veneto (TV), Italy, [2]APAT, Roma, Italy, [3]JRC, Ispra (VA), Italy.

## INTRODUCTION

Soil is a vital and largely non-renewable resource which is increasingly under pressure. Many EU policies (for instance on water, waste, chemicals, industrial pollution prevention, nature protection, pesticides, agriculture) are contributing to soil protection. But as these policies have other aims and other scopes of action, they are not sufficient to ensure an adequate level of protection for all soil in Europe. For this reason, the Commission adopted a Soil Thematic Strategy (COM (2006), 231) and a proposal for a Soil Framework Directive (COM (2006), 232) with the objective to protect soils across the EU.

The Soil Thematic Strategy outlines major soil ecological functions - such as food and other biomass production, storing, filtering, and transformation, habitat and gene pool, physical and cultural environment for mankind, source of raw materials - and points out main soil threats such as erosion, salinisation, organic matter decline, compaction, and landslides.

Furthermore, new CAP Regulations (Reg. (CE) n.1782/03) have introduced some specific measures to pursue the objectives of environmental protection policy in the EU rural areas.

To achieve a sustainable use of soil, high quality information together with harmonized assessment tools are needed. The major bottleneck for soil condition assessment, based on already existing data, is the lack of comparable methodologies for soil survey, mapping, monitoring and risk assessment. The Thematic Strategy for Soil Protection itself envisages a more harmonised monitoring approach and methodology.

SIAS (that states for Development of Soil Environmental Indicators) is a pilot project developed in Italy, that is promoted by the National Environmental Protection Agency (APAT) and involves Regional Soil Survey Services and the European Soil Data Center (ESDAC, at the EC DG JRC, Ispra). It applies a new approach that exploits soil data and expertise available at local level, being the first experiment at National level aiming at the development of the Multi-Scale European Soil Information System (MEUSIS). All Italian regions are involved in the project and they are required to assess two soil status indicators (soil organic carbon content and soil loss) in order to build up a technical tool to support knowledge about two of the main threats for European soils (erosion and organic matter decline)

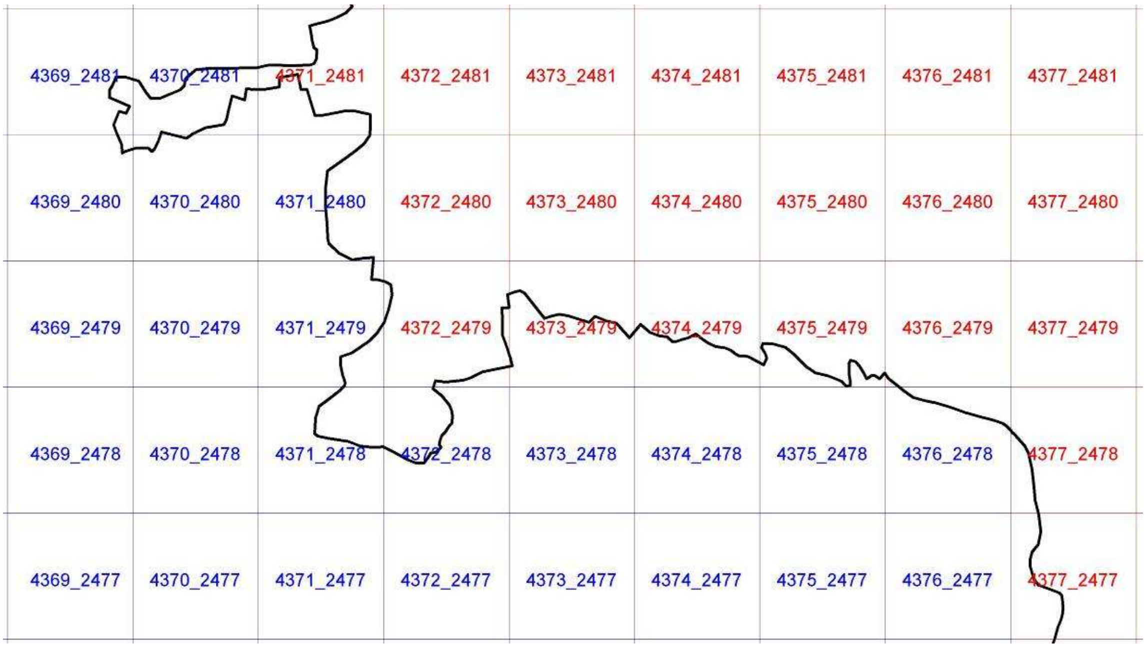
The project structure requires that the most accurate and up-to-date soil data are used and worked out directly by institutions and experts involved in soil survey at local level. This information will then build a coherent picture, useful at national level since it is harmonized according to a common infrastructure for data sharing.

## MATERIALS AND METHODS

The exchange infrastructure provides a geographical structure for georeferring data, a database for data storing and an explanation guide with harmonized codes, suggested methodologies and examples.

From a geographical point of view, output data are represented by means of a reference grid which is built following the recommendations resulting from the 1st Workshop on European

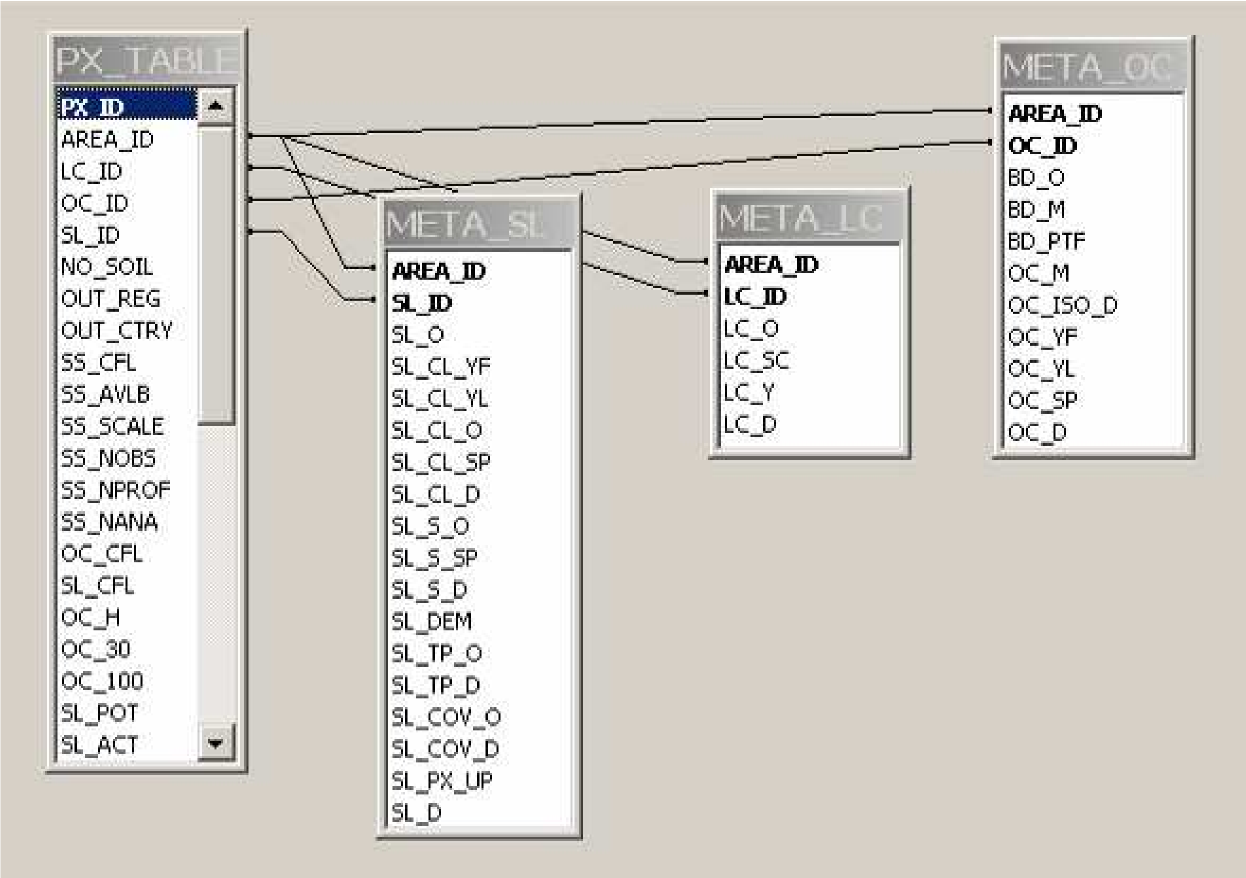
Reference Grids in the context of the INSPIRE Directive. This directive promotes the availability of harmonized geographic information and provides European standard reference grids and projection systems, with different cell resolution, depending on the requirements and the extension of the area.
For the SIAS project, the national grid is made of 1 km-sized pixels which seemed to be the best compromise between information quality, operability and goals of the project. The grid covering the whole Italian country was provided by ESDAC in ETRS89 Lambert Azimuthal Equal Area projection and it was divided into regional grid sections, avoiding any overlapping between bordering regions by assigning pixels to the region to which the dominant surface of the pixel belongs. According to this, no pixel can belong to more than one region and each region can only have full pixels (picture 1). This approach will help the final pixel merge of all Italian regions.
During the working out phase, it was suggested to each region to convert their grid section into own regional projection systems, in order to allow the overlaying with any other available regional information layer.




**Picture 1**: European Reference grid and pixel codes at the borderline between two regions (Lombardia=blue, Veneto=red). The pixel is assigned to the region with the prevalent area.

## Database Structure

Besides the geographical structure, an exchange format for storing data and metadata information has been set up jointly by the working group.
The main table of the database (**PX-TABLE**) stores information for each pixel concerning the two indicators (soil organic carbon stock and soil loss), pixel coverage and information quality. The section called *pixel coverage* describes for each pixel how much surface is covered by soil, by non-soil, how much is out of region and/or out of country borders. This information is very useful to work out the final value of the indicator in the pixel as weighted average of soil and no-soil pixel parts.
Great effort has been set in the definition of shared *data quality indicators*, both as quantitative indexes of data availability in the pixel (number of available observations, number of analyzed observations, scale of available soil maps, etc.) and specific confidence levels for each indicator in each pixel.



**Picture 2**: exchange format structure for storing data and metadata (database).

Three tables are dedicated to metadata (picture 2). They are the project value-added information since special emphasis of the project lays on exploitation of local expert judgement, in order to apply a "bottom-up" approach. Through these metadata tables, local experts can follow the most adequate assessment procedures up to their judgement (to cope, for instance, with different levels of data availability and/or reliability) but all procedure paths are required to be recorded. According to this, the sections of the exchange format regarding metadata and soil information quality acquire great importance: any kind of input data or assessment procedure is described according to codified paths and it is stored as metadata (table 1).

**Table 1**: example of metadata table, recording organic carbon stock assessment procedure paths.

| META_OC | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **AREA_ID** | **OC_ID** | **BD_O** | **BD_M** | **BD_PTF** | **OC_M** | **OC_ISO_D** | **OC_YF** | **OC_YL** | **OC_SP** | **OC_D** |
| ITD3 | 1 | B | 1 | 08 | 1 | Correlation to ISO method, built with the results of 8 public Italian laboratories x 4 samples x 3 ripetitions = 96 data | 1993 | 2007 | A1 | Method used for mountain areas, with few available data.<br>O.C. % values used for STUs are modal values of profile horizons with high correlation degree to the STUs<br>Bulk density is estimated by pedo-transfer functions calibrated on local data, using sand, clay and O.C. data. |
| ITD3 | 2 | B | 1 | 08 | 1 | Correlation to ISO method, built with the results of 8 public Italian laboratories x 4 samples x 3 ripetitions = 96 data | 1993 | 2007 | C3 | Method used for plain areas where the number of data allows the application of geostatistical analysis. Data used: observation O.C.%, measured bulk density (where available), estimated bulk density by means of pedo-transfer functions calibrated on local data, using sand, clay and O.C. data.<br>Geostatistical analisys calibrated in SMUs by means of O.C. modal values of functional groups, built according to rock fragment content, texture, drainage, mollic/organic horizon presence. |

**Soil organic carbon indicator**

Organic carbon stock is calculated for three different layers, 0-30 cm, 0-100 cm and hologanic layers (i.e. layers dominated by organic material consisting of undecomposed or partially decomposed litter, that has accumulated on the surface and is not saturated with water for prolonged periods), going through the following steps:

- standardization of organic carbon analytical data, converting local methods into ISO method results;
- evaluation of carbon stock (ton/ha) for each soil 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 (ton/ha);
o.c.= horizon organic carbon content (%);
b.d.= fine earth bulk density (g/cm$^3$);
depth = horizon depth (cm) within the given section;
sk = horizon rock fragment content (%);
n = number of horizons within the given section.

- evaluation of soil profile or STU organic carbon for the three required layers ("holorganic layers", 0-30 cm, 0-100 cm) through database programming language;
- generalization of profile/STU organic carbon content in the pixel: this step can be approached in different ways, up to each regional situation (weighted average of STUs in the SMU, by means of single profiles in the SMU or in the pixel, geostatistical analysis, etc.).

**Soil Loss Indicator**

Concerning soil loss, each region was required to choose its own method. Most of them applied USLE/RUSLE model, since it is the most common and experienced model. Also qualitative models, as CORINE erosion, were applied by some regions, due to lack of input information and experimental data to calibrate more sophisticated models. The exchange format requires both potential and actual soil loss (ton/ha) assessment for each pixel. The used model and all input variable layers (land cover, climate, morphology, soil characters, etc.) are described in the metadata section of the exchange format.

## RESULTS

The outcomes of the project can be divided into different categories, corresponding to the different stages of the project itself.

The first stage was characterized by meetings and virtual information exchanges among partners in order to set up a common infrastructure, dealing with very different regional requirements and soil data availability. During the first months of the project the exchange format changed a lot, developing from first simplified version to a much more sophisticated and shared one, as partners contributed with suggestions. Furthermore, the European Reference Grid for the Italian territory was divided into regional sections. The main results of this stage were a definitive shared infrastructure tested by most regions in their own environment and a cartographic grid section to be filled in for each partner of the project.

The second stage concerned the assessment of soil indicators and the filling in of regional databases, following the guidelines of the exchange format. In this phase each region could choose the most adequate methods and models, recording the steps in the metadata section of the exchange format. Therefore different approaches for different local situations characterized this stage. The results are anyway expressed as indicator values for the 1 km pixels.

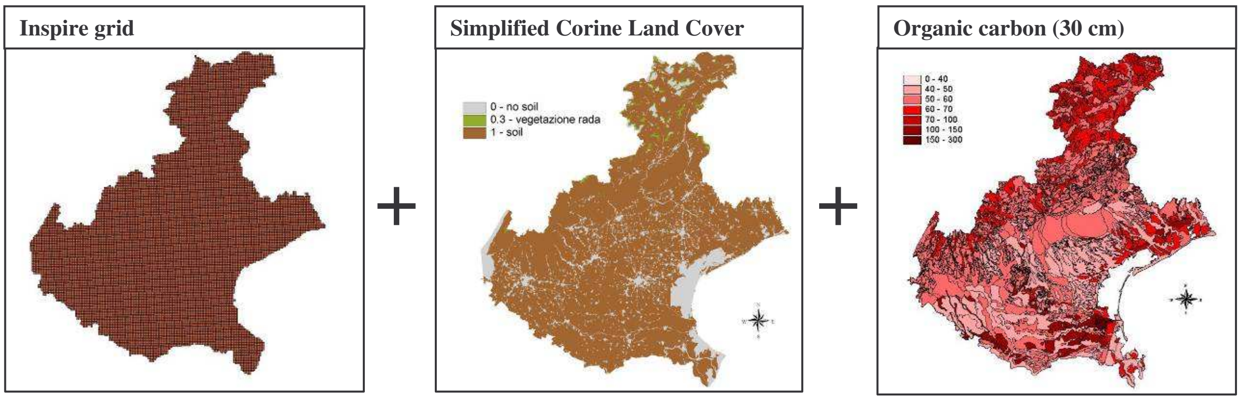
**Organic carbon stock: Veneto region example**

In Veneto region, the approach to organic carbon stock evaluation was different for the mountain area and the plain, depending on the difference in observation density. The Soil Map at scale 1:250.000 covers the whole region, but in the plain area more detailed maps are available and the observation density is always higher. According to this regional situation in the Veneto mountain area carbon stock was calculated by means of weighted average of STUs in the SMU, while in the alluvial plain the geostatistical analysis, which take into account the geographic contest to which the variables belong (SMU), could be applied.

*Mountain area*

The procedure required the overlaying of four layers projected in the same coordinate system (picture 3).

1. the shape file of the European Reference Grid concerning the Veneto region.
2. a simplified land use map: Corine Land Cover 2000 was reclassified as a "soil/no-soil" layer, according to the rules shared by the working group and codified in the exchange format;
3. a soil map with OC data for each STU;
4. a layer which defines the territory inside and outside the region, the latter specified as "extra-region", "extra-country" or "sea".




**Picture 3**: three of the four layers to be overlaid to obtain the final organic carbon stock in the pixel .

The resulting shape file records the area, the belonging European Reference Grid code and the SMU code (or "no-soil" designation) for each map polygon fraction and for each output layer (humus, 0-30 cm, 0-100 cm). Each SMU includes more STUs, whose carbon content is known so that the value of carbon stock in the pixel can be calculated as weighted average of all SMU fractions located in the pixel (table 2). The pixel fractions located out of national borders or defined as "no-soil", are treated as poligons with no organic carbon stock; this means that pixels with very low O.C. indicator values turn up to be either areas with actually low carbon stock or pixels that include a pattern of large "no-soil" surfaces with local organic carbon accumulation areas (i.e. high altitude belts with thick organic horizons but also with lots of bare rock).

Table 2: example of OC stock calculation for pixel “4525_2618” with two SMU fractions and no-soil areas

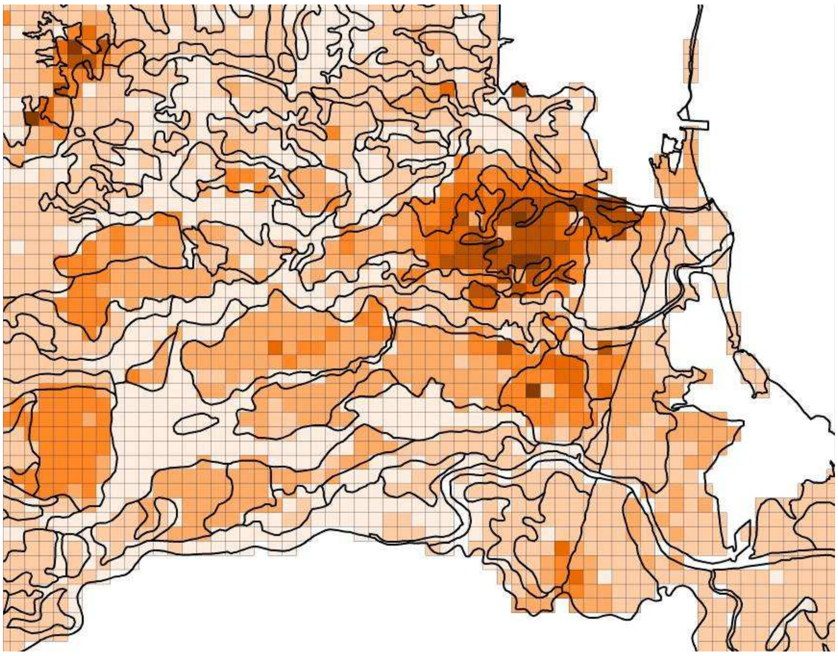
| PIXEL | SMU CODE | OC (t/ha) | AREA (%) |
|---|---|---|---|
| 4525_2618 | SMU1 | 80 | 70 |
| 4525_2618 | SMU2 | 50 | 25 |
| 4525_2618 | no-soil (sea or extra-country) | 0 | 5 |
| | | | Total 100 |
| **OC value assigned to the pixel: 80*70/100 + 50*25/100 + 0*5/100 = 68.5 t/ha** | | | |

*Plain area*

In the plain area many detailed soil survey maps were available so that the application of geostatistical analysis for data spatialization was possible (picture 4).

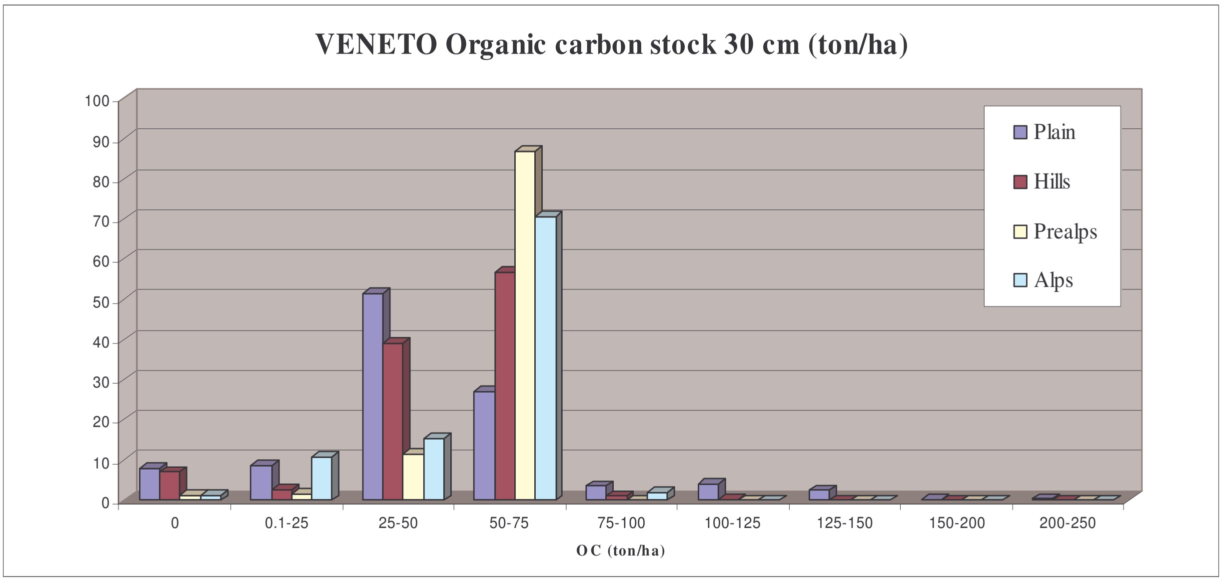
The row data included single observation organic carbon percentages, measured bulk density (where available) and estimated bulk density calculated by means of pedo-transfer rules, set up and calibrated on regional data, using clay, sand and organic carbon contents.

STUs and their observations and then were grouped into so called “organic carbon functional groups”, according to some characters influencing organic carbon dynamics in soils (i.e. rock fragment content, surface texture, drainage, mollic/organic horizon presence), and their significance was tested using statistical analysis. Through the geostatistical approach organic carbon values of functional groups are spatialized according to statistical rules which take into account the spatial structure of the variable and mean organic carbon contents of the geographic contest to which the variables belong (SMU), as reference thresholds. The final result is the average organic carbon stock for 1 km pixels for each layer (holorganic layers, 0-30 cm, 0-100 cm).



**Picture 4**: detail of geostatistical 1 km pixel spatialization in the Veneto alluvial plain, for organic carbon stock 30 cm. The black delineations are mapping units from the 1:250.000 scale map.

The results for the whole region (picture 5) were grouped into four homogeneous environments, having different carbon stock trends. Most of the territory has a 0-30 cm carbon stock between 25 and 75 ton/ha. Alluvial plain pixels (about 50%) are mostly included in the 25-50 ton/ha class and few pixels have very high organic carbon content (up to 250 ton/ha) mainly peat-bogs and reclaimed lands. The value is an average in the whole pixel, so that non soil areas (urban areas, water, bare rock, etc.) are also included. That’s the reason why most pixels of the pre-alpine belt match the class 50-75 ton/ha while about 25% of alpine pixels, where climate should facilitate soil organic carbon accumulation, have lower values. As a matter of fact, pre-alpine areas are covered by forests and are little urbanized while alpine environment reaches higher altitudes where soils with high organic carbon content are associated with wide areas covered by bare rock and deposits with no organic carbon.

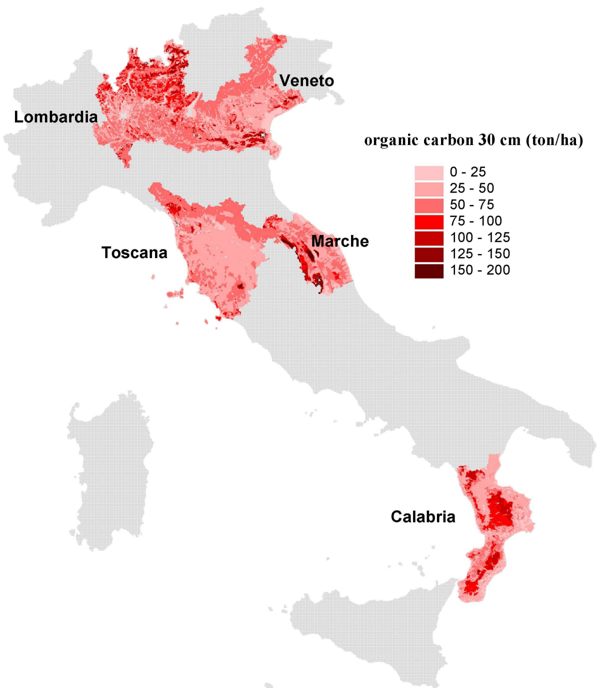



**Picture 5**: percentage distribution of pixels of different environment within organic carbon classes (Veneto)

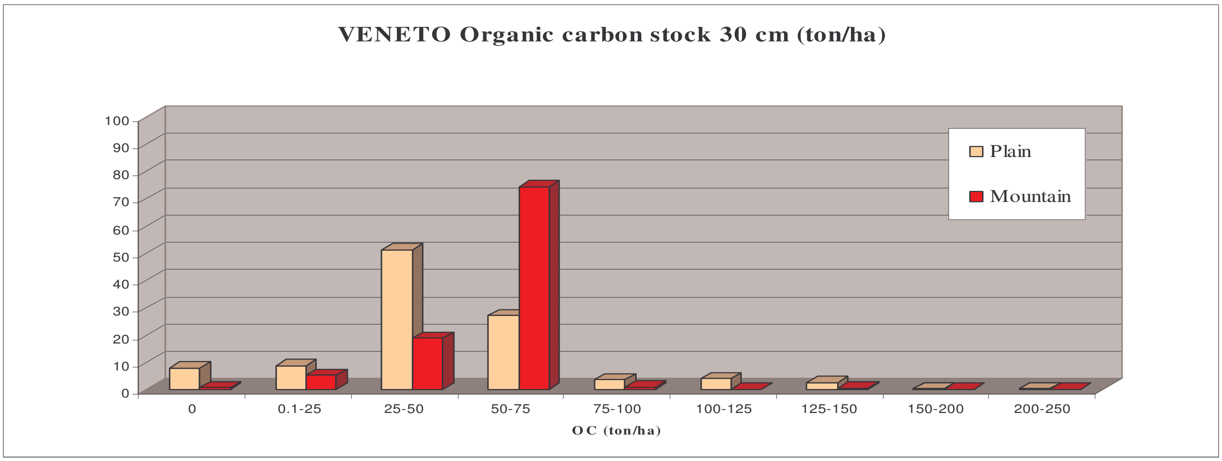
## Other region examples

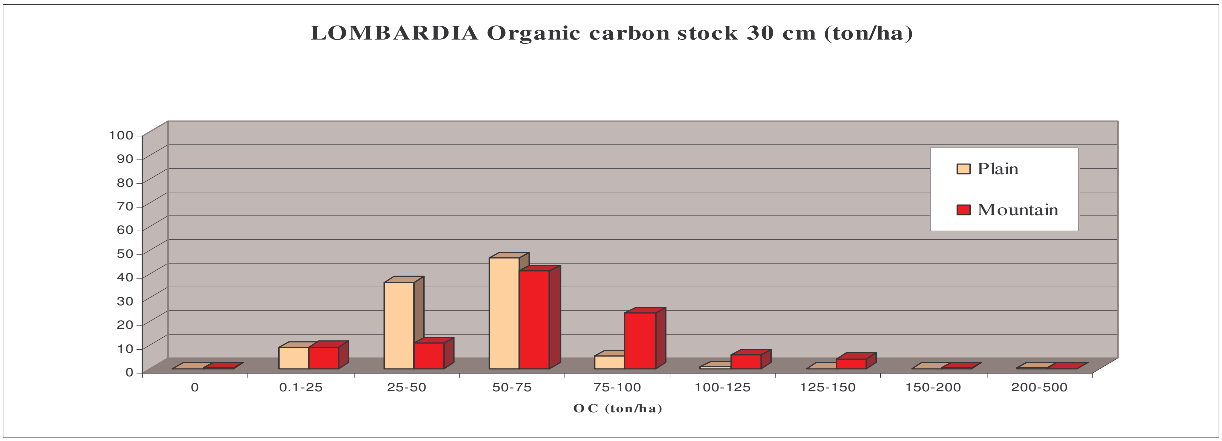
The example shown below concern few examples of regional organic carbon stock indicators, which are available at the present stage of the project.

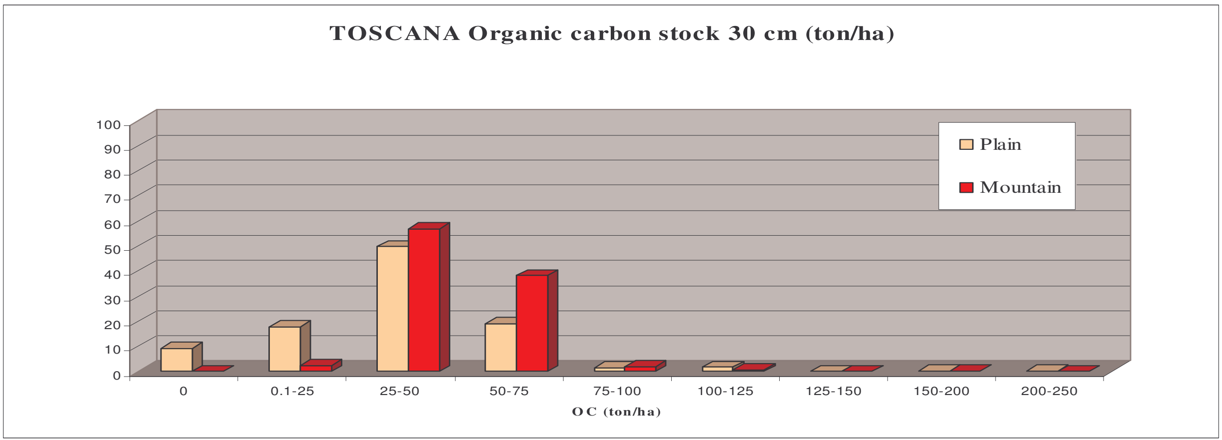
The graphs below show the distribution of pixel values for the considered regions, expressed as organic carbon indicator classes.

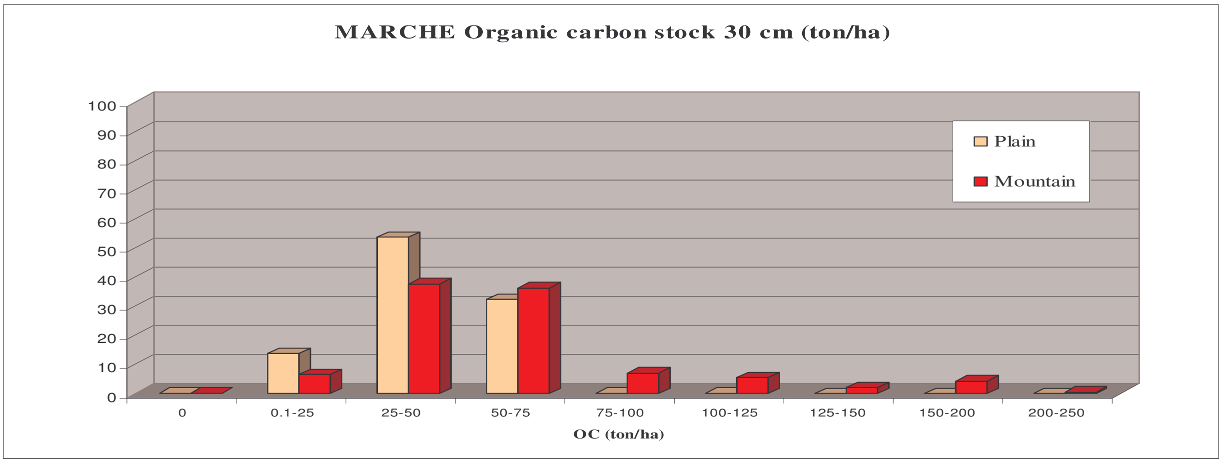


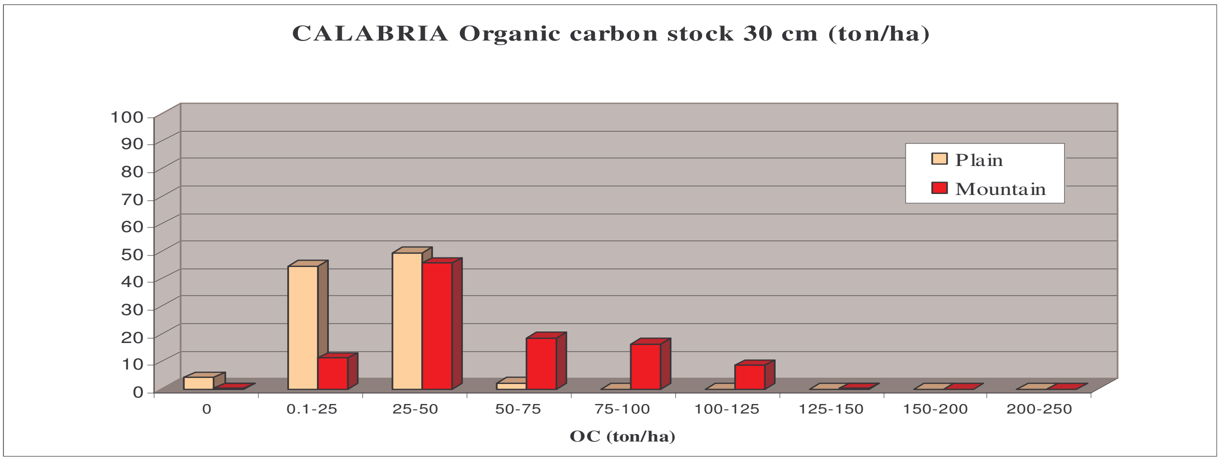

**Picture 6**: organic carbon indicator results for some Italian regions


VENETO Organic carbon stock 30 cm (ton/ha)
100
90
80
70
60
50
40
30
20
10
0
Plain
Mountain
0
0.1-25
25-50
50-75
75-100
100-125
125-150
150-200
200-250
OC (ton/ha)


LOMBARDIA Organic carbon stock 30 cm (ton/ha)
100
90
80
70
60
50
40
30
20
10
0
Plain
Mountain
0
0.1-25
25-50
50-75
75-100
100-125
125-150
150-200
200-500
OC (ton/ha)


TOSCANA Organic carbon stock 30 cm (ton/ha)
100
90
80
70
60
50
40
30
20
10
0
Plain
Mountain
0
0.1-25
25-50
50-75
75-100
100-125
125-150
150-200
200-250
OC (ton/ha)


MARCHE Organic carbon stock 30 cm (ton/ha)
100
90
80
70
60
50
40
30
20
10
0
Plain
Mountain
0
0.1-25
25-50
50-75
75-100
100-125
125-150
150-200
200-250
OC (ton/ha)




**Picture 7**: percentage pixel distribution for some Italian regions, divided into plain and mountain environments within organic carbon classes.

Veneto and Lombardia alluvial plains have comparable trends, while in Lombardia mountain area organic carbon stock is higher, compared to Veneto, due to different geo-pedological conditions: higher altitudes, colder climate, less bare rock surfaces compared to Veneto dolomitic landscape, support higher organic carbon content in Lombardia mountain soils. Moving towards the south of the country, climate and pedo-geological conditions change, Marche and Toscana region have a central location and mostly a hilly and mountainous territory, while Calabria region, since it is located in the deep south of the country, has a more Mediterranean climate and a mountainous territory. A Mediterranean climate does not support organic carbon stock processes but mountainous climate and forest environment do. In the different regions, pixel organic carbon values result as combination of these tendencies (picture 7).

**Soil Loss: Veneto region example**

In Veneto region, soil loss was assessed by means of USLE model, which is based on the following equation:

$$A = R \cdot K \cdot L \cdot S \cdot C$$

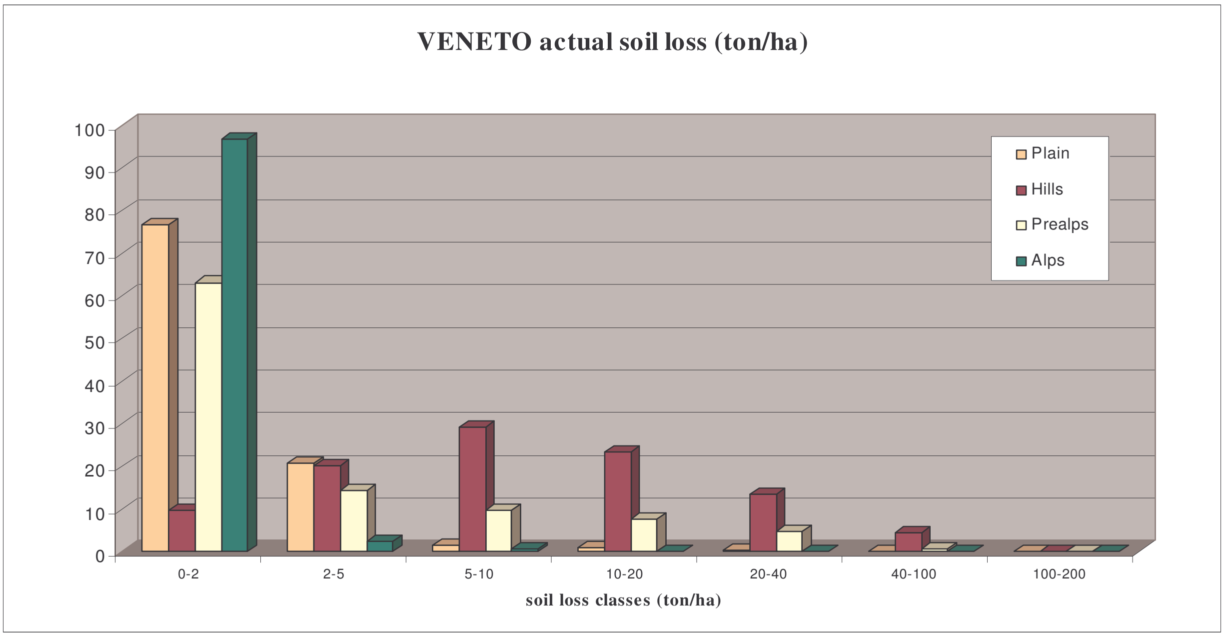
where:
A: soil loss by water erosion (ton·ha$^{-1}$·year$^{-1}$);
R: rainfall erosivity (MJ·mm·h$^{-1}$·ha$^{-1}$·year$^{-1}$);
K: soil erodibility, that means soil loss per R unit (t·h·MJ$^{-1}$·mm$^{-1}$);
L: slope length (adimensional);
S: slope angle (adimensional);
C: land cover factor (adimensional).

- R Factor was calculated starting from 5 minute frequency rainfall data, available for 12 years, according to Brown and Foster equation (1987).
- K Factor is strictly connected with soil characteristics and it has been calculated extracting texture, organic carbon content, permeability and structure soil data from the soil regional database at scale 1:250.000, according to the Handbook 703 (Renard et al., 1997).
- LS Factor depends on the morphology of the area. Among different approaches, Moore and Burch’s (1986) has been chosen as it gave the best results, according to expert judgment. This approach introduces the concept of “specific catchment area” instead of the linear

length of the slope, calculated by means of the ArcGis tool "Hydrology". The regional DTM used has a 30m resolution.

- C Factor is a very complicated factor to be calculated since it varies in time and requires lots of information about cultivation practices. Since these data are not available for Veneto region Corine Land Cover classes have been correlated to C factor values, according to bibliographic examples (Bazzoffi, 2007, Bartolini et al., 2004, Rousseva e Stefanova, 2006, Suri et al, 2002, Wischmeier. e Smith, 1978). In order validate the applicability of these relations for Veneto environment, C factor for corn land use (very common crop in Veneto region and for which also cultivation data are available) has been calculated by means of the official USLE method and compared to bibliographic values.

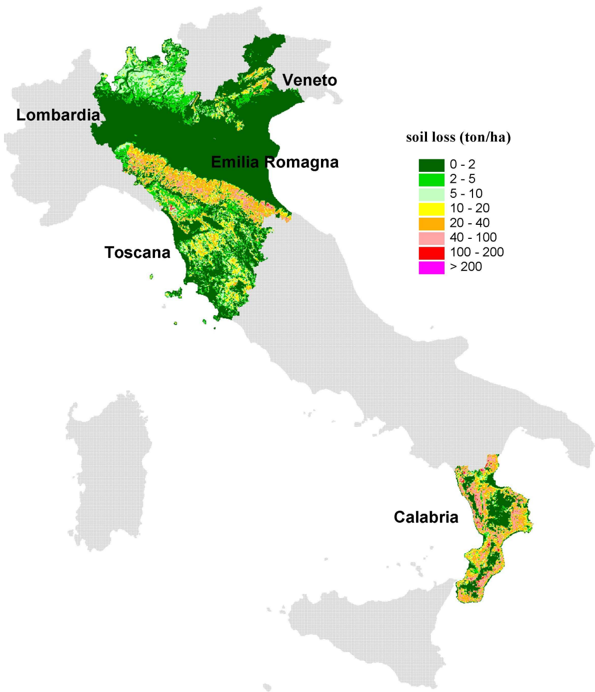
The graph of picture 8 highlights that Veneto region is not interested by important soil loss for most of its surface. Alpine areas, which are mostly covered by forests and pastures have no or very low erosion, while the only areas with some relevant soil loss are lower mountains and particularly hilly landscapes which are often cultivated slopes.



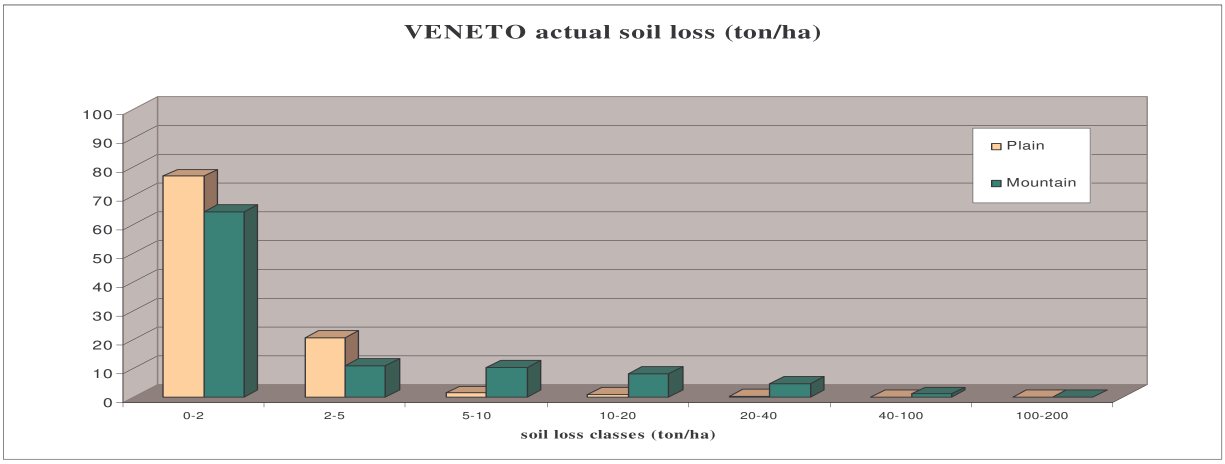

**Picture 8**: percentage distribution of pixels of different environment within soil loss classes (Veneto)

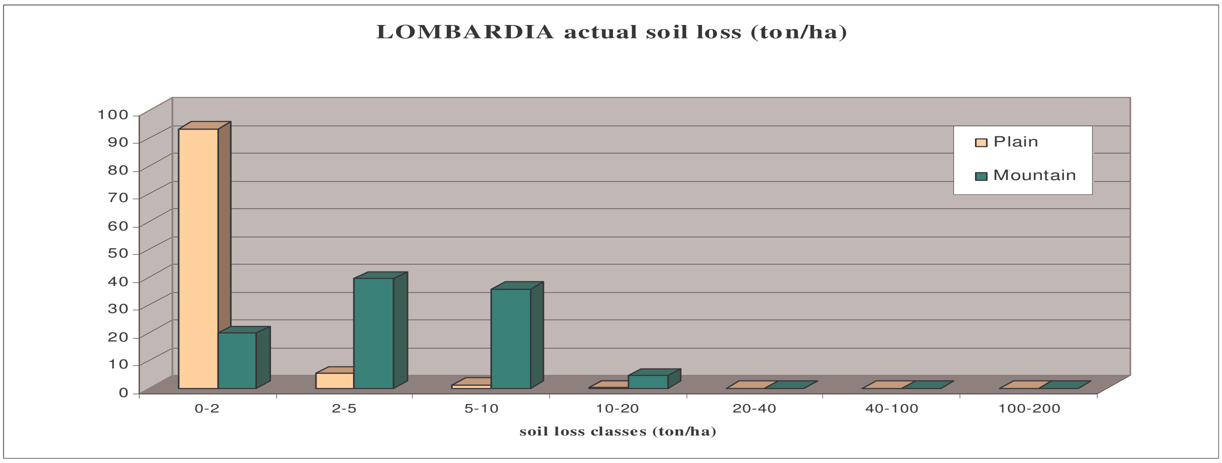
## Other region examples

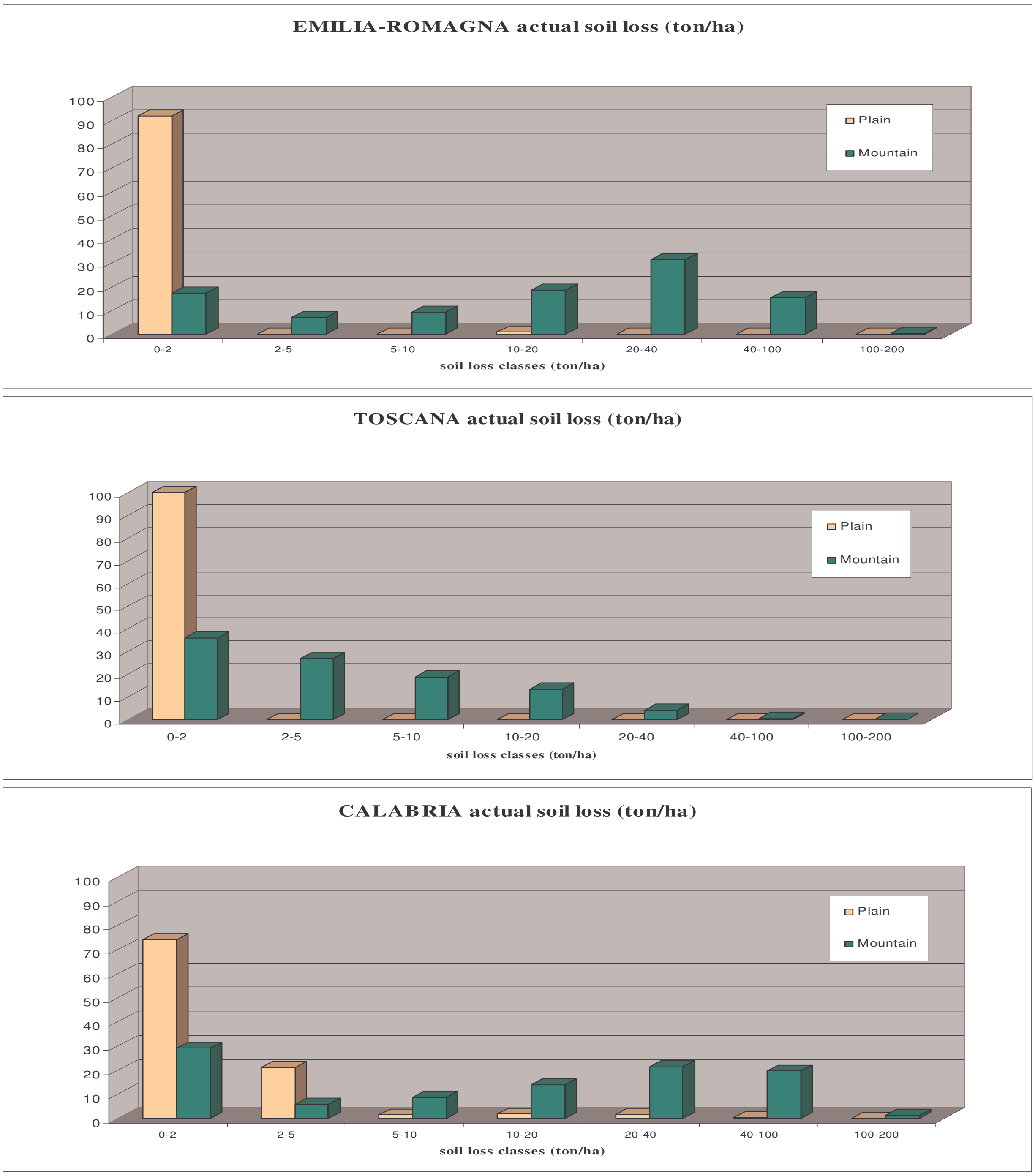
The example shown below concern few examples of other region soil loss indicators, which are available at the present stage of the project.
The graphs below show the distribution of pixel values for the considered regions, expressed as soil loss indicator classes.




**Picture 9**: results of soil loss indicator for some Italian regions






**Picture 10**: percentage pixel distribution for some Italian regions divided into plain and mountain environments within soil loss classes.

Very different situations could be highlighted in the above considered regions (picture 10): while Veneto and Lombardia mountain regions belong to alpine environment with forests and pastures protecting soil from erosion processes, Emilia Romagna and Toscana Appennines have generally lower altitudes and more erodible soils. In these areas human induced soil loss is also relevant, due to agricultural practices which are often applied even on steep slopes. The situation could be compared not to Veneto alpine environment but more likely to Veneto hilly areas, where soil loss can reach the highest values in the region (20-40 ton/ha).

An even more different situation is represented by Calabria region, located in the south of the country. Most of the regional territory is mountainous and climate, pedo-geological conditions and landscapes are very different. As a result, soil loss processes are much more important than in the previous examples and in some pixels they reach over 100 ton/ha..

## CONCLUSIONS

Experimental application of the shared exchange format by the Italian regions to their own territory is now at the final stage. Once all region results will be collected, there will be the final merge of all grid sections in order to have a complete harmonized picture of organic carbon stock and soil loss for the whole country.

The different stages of the project have been characterized by different kinds of problems.

At the beginning the main difficulties to deal with, had to do with correlation, active involvement and participation among partners, since the starting point of the different Italian regions, i.e. soil data availability, regional soil knowledge, data processing experience, etc. were in some case far apart from each other. It hasn't been easy to define a shared infrastructure to assess two soil indicators, that could represent a first important meeting point among different regional situations and requirements.

Once the common infrastructure has been shared and accepted, all regions had to face technical problems applying it to each specific contest. Technical experience seemed to vary a lot among regions so that a main group of more expert regions found themselves to be a technical guide that first reached a practical result and could then help other regions to deal with specific situations. Some main technical difficulties occurred for most partners regarding bordering areas (sea, out of region, out of country), choice of input data format (vector vs raster formats), information layers with no overlapping borders (Corine Land Cover, regional soil maps), projection system conversions, choice of best erosion models. For the running final phase some problems are going to come out, dealing with different section merge and indicator result comparability and harmonization, particularly on bordering areas. Up to local experts, 1 km pixels seem to represent well regional situations and indicator trends. As final step, though, some kind of result harmonization among regions will be necessary before merging all regional databases in order to provide an effective and validated national tool.

Besides the great practical importance of producing a first set of national indicators which can be used to support national and European level technical decisions, the great meaning of this project lies in the exploitation of local expertise: this can guarantee the use of the most up to date information and the more reliable assessment obtaining a national harmonized and shared result, according to the bottom-up approach. Furthermore the partner cooperation net that has been created in this occasion, can be the ground for other initiatives that will be certainly facilitated by the already set up working group.

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