Chapter 18
Soil Conservation

Paolo Giandon

Abstract Soil fertility relies primarily on the presence of organic matter in soil, as it is the substrate for the vital processes needed for plant growth. Organic matter is the most important component of soils because of its influence on soil structure and stability and it plays the principal role in maintaining soil functions. For many relevant problems, such as physical soil degradation, soil carbon (C) concentrations in the topsoil are more meaningful than total carbon content. From the C storage point of view (C sequestration), ideally, changes in the SOM should refer to equivalent soil masses (C stocks).

Keywords Topsoil • Conservation • Soil organic matter (SOM)

18.1 Definition

Soil is the result of a combination of weathered parent material, climate influence on physical site factors, and vegetation, which affect soil properties by adding organic matter to the soil. Soil development depends on various processes, the key ones of which are the decomposition and accumulation of organic matter.

The physical and chemical characteristics of soil are strictly related to the quality and quantity of organic materials and the way they are linked to and aggregated with mineral soil to build up the so-called organo-mineral complexes, which constitute the main active surfaces with respect to interaction with solutes of soil water and with living organisms.

Soil fertility relies primarily on the presence of organic matter in soil, as it is the substrate for the vital processes needed for plant growth. For this reason, we can assume that soil conservation is attainable only through preventing the depletion of the soil's organic matter and maintaining its concentration at a level higher than the minimum that is required for soil conditions to be adequate for plant growth.

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Therefore, the practices that comply with the aim of soil conservation are those that permit an adequate level of organic matter concentration to be maintained, that is, the concentration needed for adequate support to plant life and growth.

Organic matter is the most important component of soils because of its influence on soil structure and stability, water retention, cation exchange capacity, ecology, and biodiversity, and as a source of plant nutrients. Soil organic matter (SOM) plays the principal role in maintaining soil functions. It has the particular function to provide the physical environment that allows roots to penetrate the soil, excess water to drain through the soil profile but sufficient water to be retained to meet the physiological demands of the plants, and the flux of gases through the soil to maintain a well aerated environment. The soil organic fraction also provides a great variety of habitats and a food source for the living organisms within the soil. These organisms are very important for the breakdown of the organic materials and the release of plant nutrients, give significant support for maintaining the physical conditions of the soil, and facilitate the plants to access nutrients from otherwise unavailable sources.

Although the quantitative evidence for critical thresholds of organic matter content is slight (Körschens et al. 1998; Loveland and Webb 2003), it is widely believed that soil cannot function optimally without adequate levels of SOM (Van-Camp et al. 2004). SOM quality is related to the nature and properties and relative proportions of different organic compounds that are part of it and their combined influence on soil functions.

From the quality point of view, attention is mainly focused on a set of attributes linked to soil functions rather than the chemical characteristics of single organic constituents. For instance, changes in SOM quality may impact soil biodiversity, transport of substances within and through the soil, water availability, microbial activity, etc. (Van-Camp et al. 2004).

Soil formation and organic matter evolution are driven by living organisms, and therefore the interaction between SOM and biodiversity is strong.

The decline in SOM is of particular concern in tropical areas. The problem is not, however, limited to these areas because the loss of SOM can be relatively high even in temperate climates (Bellamy et al. 2005).

Several of the factors responsible for a decline in SOM are related to human activity: conversion of grassland, forests and natural vegetation to arable land, deep ploughing and other intensive tillage operations of arable soils, high application rates of nitrogen fertilizers that increase mineralization of organic matter, cultivation of peat soils, crop rotations with reduced proportion of grasses, soil erosion, and wild fires (Kibblewhite et al. 2005). Declining organic matter content in soil is also strongly associated with ongoing desertification.

18.2 Soil Conservation Description and Monitoring

The factors that control the dynamics of organic matter in the soil determine the changes in the SOM content. Some of these factors are inherent soil properties, such as the clay content, which protects organic matter against mineralization and therefore influences the rates of change in organic matter content; others are external, such as climate, or human-induced factors, for example, land cover, land use, agricultural practices, etc.

SOM levels and its nature and quality determine different soil functions. There are still gaps in our detailed knowledge and understanding of the nature, properties, and ecological significance of the overall SOM levels and its different pools, despite the fact that this topic area has been the subject of considerable research over many decades.

There are also still many gaps in our knowledge with respect to the relationships between SOM levels and quality and soil biodiversity nature and function. While the maintenance and improvement of biodiversity are recognized to be an important target of current policies and conventions, it is important to establish the roles of a diverse community of organisms within the soil.

There is a need to establish the nature of the relationships present under a range of conditions, how these relationships vary across them, what the natural variations in these relationships are, and how stable the relationships are under climate and environment changing scenarios (Smith 2004).

To assess the change in total SOM in agricultural land, changes not only in its concentration but also in bulk density and ploughing depth have to be taken into account. However, for many relevant problems, such as physical soil degradation, soil carbon (C) concentrations in the topsoil are more meaningful than total carbon content. From the C storage point of view (C sequestration), ideally, changes in the SOM should refer to equivalent soil masses (C stocks). In that case, reliable information on the bulk density and stone content of soils is required.

Although significant time scale changes of SOM were observed only in the topsoil of arable land, deeper soil layers should be investigated as well.

Since the topsoil is the most important part for crop and forest production, and it shows a high spatial and temporal variability (Jones et al. 2004), a careful and accurate description of the morphological topsoil properties offers important initial information for assessing the SOM status and quality, and thus for observing the effects of soil management.

Since most existing classifications focus mainly on stable subsoil properties, a new and comprehensive rationale for classifying topsoil properties was developed (FAO 1998). Exemplary parameters are soil color, distribution of coarse roots, ectohumus horizons, stone content, thickness of humus horizons, etc.

In particular in forests, but also in grassland and cropland topsoils, humus forms/humus types characterize the topsoil morphology on the basis of genetic and/or functional properties in a holistic manner. The well established national systems (Baritz 2003; Katzensteiner et al. 1999) of humus forms should be included in any monitoring system that focuses on SOM, especially in extensively managed ecosystems such as pastures and, in particular, forests.

18.3 Indicators

18.3.1 Organic Matter Status Indicators

There is wide concern in the world about the possibility that the decline in organic matter in the soils in intensively cultivated areas could lead to an irreversible decline in soil fertility, structural stability, and biodiversity. Total soil organic carbon is an overall measure of the state of the soil, and responds relatively rapidly (<10 years) to changes in pressures, and thus, it could be considered as a response variable. Organic carbon and nitrogen are widely measured as standard properties in most soil laboratories. They give a broad indication of the soil capacity to host biodiversity. Considering bulk density allows adequate comparisons of data between different soils.

For general purpose monitoring of SOM decline, it is recommended that the following parameters are measured:

- Total organic carbon,
- Total (organic) nitrogen,
- C:N ratio (derived from the previous two),
- Bulk density.

Successive evaluations lead to only organic carbon being considered, as nitrogen content is not a parameter that can give information about SOM status.

Therefore the following two main indicators can be proposed:

- Topsoil organic carbon content,
- Soil organic carbon stocks.

The topsoil organic carbon content indicator has some advantages:

- It can be measured directly,
- It is an indicator that is relevant to the potential risk of soil erosion and soil biodiversity decline, as well as to desertification,
- Data on the organic carbon content in topsoils are available in most countries.

At the same time some disadvantages can be underlined:

- Data are dispersed, not always easily accessible, and not harmonized;
- Discrepancies between data from different regions or countries can arise from differences in analytical methods and/or in sampling depth;
- As changes in soil organic carbon content are rather slow, the minimum time interval over which changes can be observed (and therefore measurements are justified) is typically > 5 years;
- As topsoil organic carbon content is highly variable in space, small changes (<5 %) at a given site cannot be detected without using a large (more than 100) number of replications (Conen et al. 2004; Smith 2004).

Soil organic carbon content is measured routinely in surface horizons during soil surveys and on experimental sites, and hence, there are sufficient data to apply this indicator at the national scale.

The soil organic carbon stocks indicator has some advantages:

- It is more relevant than organic carbon content for assessing the role of soils in the global C cycle and monitoring overall changes in SOM,
- It can be calculated from two direct measurements,
- Measurement of density is also relevant to the risk of soil compaction, soil biodiversity decline, and desertification.

On the other hand, soil organic carbon stocks require a greater sampling effort because of the need to determine bulk density, which is even more spatially and temporally variable than organic carbon content, particularly in soils under arable crop use. It is an important indicator of soil condition, especially under the influence of climate change.

18.3.2 Organic Matter Dynamic Indicators

The European Commission (Joint Research Centre) developed a set of Soil Organic Carbon Status Indicators (SOCSI) to support the EU policies related to SOC (Stolbovoy 2008). It was set up in order to investigate OC trends in different soil types and land uses. The SOCSI are knowledge-based and can be derived from available soil data at a regional scale. SOC content results from the combination of the Soil Typological Unit (STU) and land use/management. Each combination has specific SOC margins and therefore the SOC content change is limited. Moreover, the potential for the change depends on the actual OC content.

When a data set for each STU is too small to allow statistical analysis, the application of SOCSI can be determined for functional soil groups obtained by grouping STUs on the basis of texture, coarse fragment content, drainage, and physiography.

The set includes:

- Data-derived parameters (mean, minimum, and maximum values),
- Knowledge-derived parameters (CSP-Carbon Sequestration Potential, PCL-Potential Carbon Loss, CSR-Carbon Sequestration Rate, CLR-Carbon Loss Rate and capability classes for OC change).

The minimum and maximum values represent the margins of the OC range of change. The potential for the change depends on the actual OC content.

According to the Joint Research Centre's procedure, the low/medium/high capability classes of CSP and PCL are defined for each functional group:

- Low (L): < [Min + (Max – Min)/3]
- Medium (M): between [Min + (Max – Min)/3] and [Min + 2(Max – Min)/3]
- High (H): > [Min + 2(Max – Min)/3]

These SOCSI can be drawn on maps (one for CSP and one for PCL) to show the areas in the low, medium, or high PCL/CSP classes.

18.4 Baseline and Thresholds Values

Quantitative relationships exist between SOM and many soil properties and functions, but these relationships are complex in nature and rarely linear in their relationships (Loveland and Webb 2003). There may be threshold values for soil organic matter content above which the function may operate optimally (for example 1.5–2 % C for aggregate stability or desertification), but the task is to establish the nature of these thresholds and the extent to which they vary with the nature of the soil mineral fractions and environmental context. These threshold values should be defined in the context of a given soil property or function, within a climatic zone, and for a given soil type (texture).

As the different SOM fractions do not have the same roles in influencing soil properties, a fractionation of organic matter may be a way to establish the nature of the relationships with soil properties, and such an approach should be adopted as part of the soil monitoring process.

It is also of critical importance to consider SOM management, because SOM turnover and decomposition play significant roles in determining many soil properties (e.g., aggregation). It is important to recognize that stabilized composts or manures do not necessarily have the same effect on these properties as fresh plant residues, which are often left at the soil surface by the new practices in agriculture; such practices may have a role in influencing soil physical properties and contributing to soil protection.

18.5 Primary Indicator: Estimation of Soil Organic Carbon Stock. A Study Case

In order to manage soil information correctly, a new approach that exploits soil data and expertise available at the local level is required, and this is the basis for the development of the Multi-Scale European Soil Information System (MEUSIS).

SIAS (that stands for Development of Soil Environmental Indicators) is a pilot project developed in Italy, which is promoted by the National Environmental Protection Agency (APAT, now ISPRA) and involves Regional Soil Survey Services and the European Soil Data Center (ESDAC, at the EC DG JRC). All Italian regions were required to assess soil organic carbon stock data in order to build up the indicator for organic matter decline. The most accurate and up-to-date soil data were used and analyzed directly by institutions and experts involved in soil surveys at the local level to build a coherent picture, which is useful also at the national level, since it is harmonized according to a common infrastructure for data sharing.

18.5.1 Reference Grid

To overcome harmonization problems across borders, it was 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 was built following the recommendations of the Eurogrid/INSPIRE Directive. For the SIAS project, the chosen grid is 1 km × 1 km in size, which seemed to offer the best compromise between the information quality, operability, and goals of the project.

18.5.2 Exchange Format

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 with an explanatory guide in which harmonized codes, suggested methodologies, and examples are collected.

Information about soil organic carbon stock and pixel coverage is stored in the so-called pixel-table. Some data quality indicators were also defined and shared by the working group, 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 as specific confidence levels for each indicator in each pixel.

The special emphasis of the project lies in the exploitation of local expert judgment (“bottom-up” approach), so that local experts can follow the most adequate assessment procedures according to their judgment (to cope, for instance, with different levels of data availability and/or reliability) as long as all the procedural paths are recorded into three metadata tables. These tables constitute the project value-added information, and any kind of input data or assessment procedure is recorded in them, both through codified items and free descriptions.

18.5.3 Methodology

Organic carbon stock (t/ha) was calculated for three different layers, 0–30 cm, 0–100 cm and for holorganic layers (i.e., formed mainly by organic material consisting of undecomposed or partially decomposed litter, that has accumulated on the surface, not saturated with water for prolonged periods), 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);
o.c. = horizon organic carbon content (%);
b.d. = fine earth bulk density of the horizon (g/cm3);
depth = horizon depth (cm) within the given section;
sk = horizon rock fragment content (%);
n = number of horizons within the given section.

In order to allow a comparable assessment, organic carbon data obtained by means of local analytical methods were converted into ISO method results, according to specific regression functions. Concerning bulk density, some regions (5 out of 12) used both measured data and the pedotransfer function (PTF); among these, 4 regions used the original PTF calibrated on their own measured dataset (Ungaro et al. 2005); the others used the PTF found in the literature.

To assess organic carbon content within the pixel, different pathways were 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. 2005; Ungaro et al. 2010). As the final step, the organic carbon stock within the pixel was intersected with a land-cover map, Corine Land Cover, or a more detailed regional map, to obtain the final value of t/ha, subtracting no-soil surfaces.

All information on methods and data (analytical-measurement methods, PTFs and regressions used, data time span, spatialization and up-scaling methods, land-cover scale and year) was recorded in the metadata section of the exchange format.

18.5.4 Results

The organic carbon stock for the two layers, 0–30 cm and 0–100 cm, for 11 regions out of 20 are shown in Figs. 18.1 and 18.2. The approaches used for organic carbon stock evaluation were different in different regions, and sometimes even in different areas of the same region, depending on data availability and observation density. In the areas where a soil map at a scale of at least 1:250.000 was available, carbon stock could be calculated by means of the weighted average of STUs in the SMU (i.e., Veneto region mountain area) or as the average value of observations within

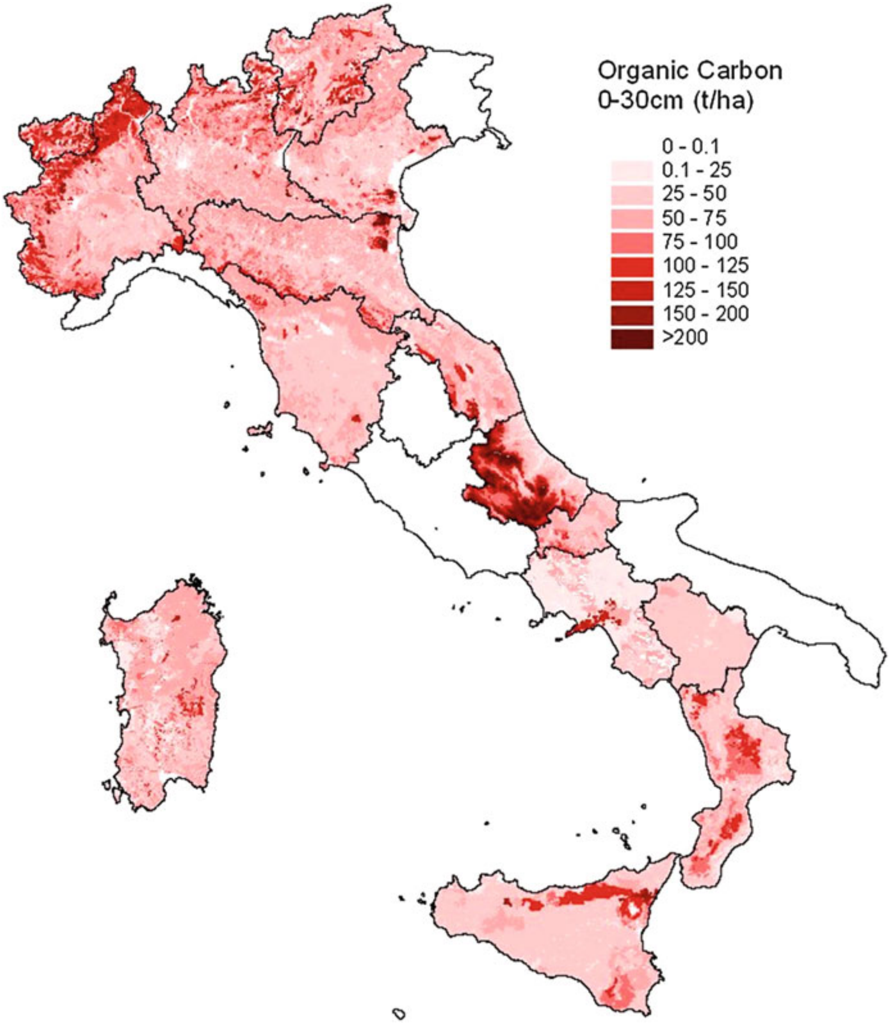

Fig. 18.1 Organic carbon stock 0–30 cm (t ha^{-1})

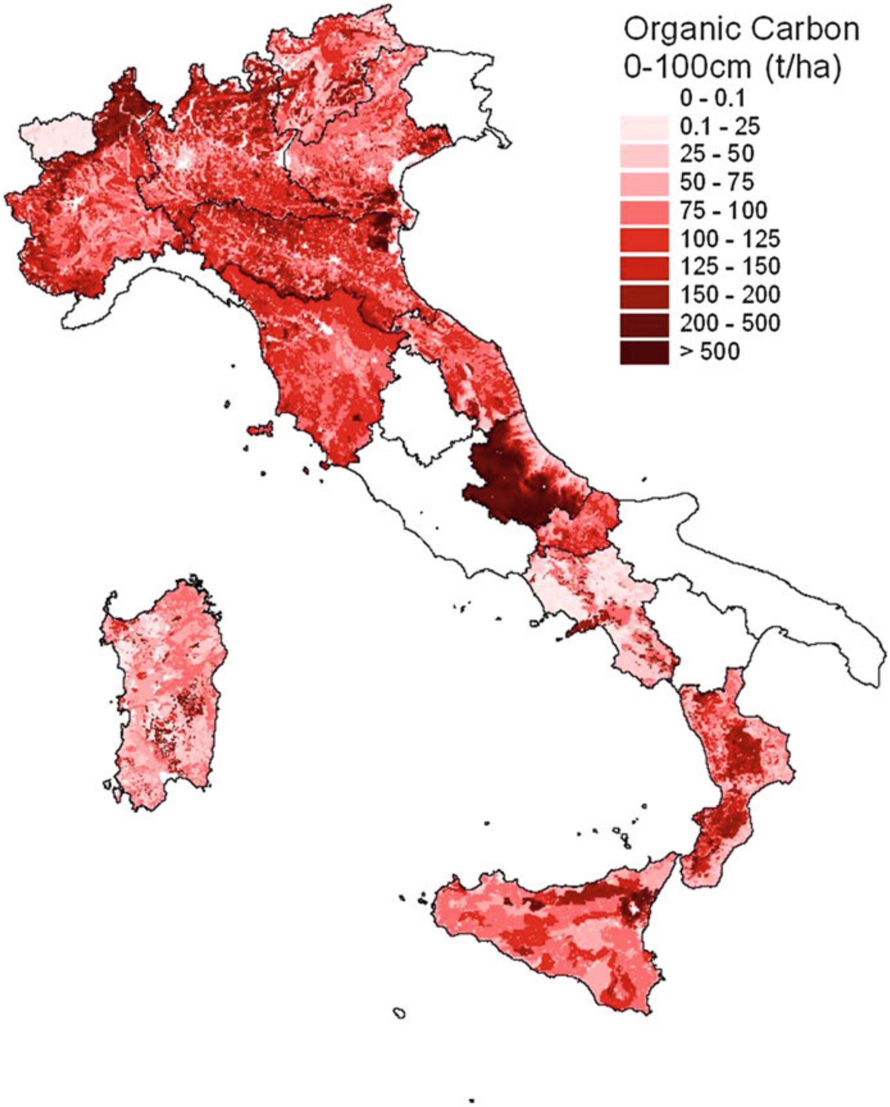

Fig. 18.2 Organic carbon stock 0–100 cm (t ha^{-1})

the SMU (i.e., Tuscany and Piemonte region). The procedure was worked out by overlaying three different layers, such as the European Reference Grid, the soil map (with attached OC data calculated for SMU), and a land cover map (simplified into a few classes, as soil, no-soil, extra-region, extra-country, and sea). All the operations were usually conducted by the regions in their own projection system, with some regions using raster layers, while others using vectors.

Where more detailed maps were available and the observation density was higher (Veneto and Emilia Romagna alluvial plain), 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. STUs and their observations were grouped into so-called "organic carbon functional groups," according to some characteristics that influence 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, functional group organic carbon values were spatialized according to statistical rules that take into account the spatial structure of the variable and mean organic carbon content of the geographic context to which the variables belong (SMU), as reference thresholds.

Bulk density assessment was found to be a weak point, since different PTFs often give very different results, strongly depending on the environment where they were developed and calibrated. Due to this variability, it was found advisable to provide the organic carbon percentage content, as well as t/ha, as required for the organic carbon soil indicator.

The graphs in Figs. 18.3 and 18.4 show the mean regional carbon stocks separately total and mountain and plain areas. According to the first results (10 regions out of 20), the average organic carbon content in plain areas ranges between 34 and 60 t/ha in the 0–30 cm section, with the lowest values in southern Italy (34 t/ha) and the highest (51–60 t/ha) in the north (Po plain). Average OC stock in the 0–100 cm section ranges from 78 to 154 t/ha in the plain, with the same geographical trend. In the Alps, the content is quite variable, from 59 to 103 t/ha, on average, for the 0–30 cm section and from 87 to 160 t/ha for the 0–100 cm section. Central and southern mountain areas (Appennini) have an average content of 50–58 t/ha within 30 cm and 95–114 t/ha within 100 cm.

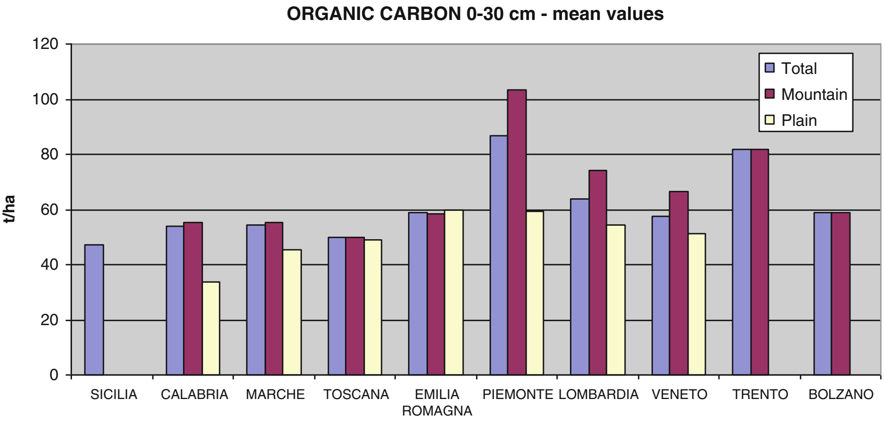

Fig. 18.3 Mean organic carbon values for 0–30 cm

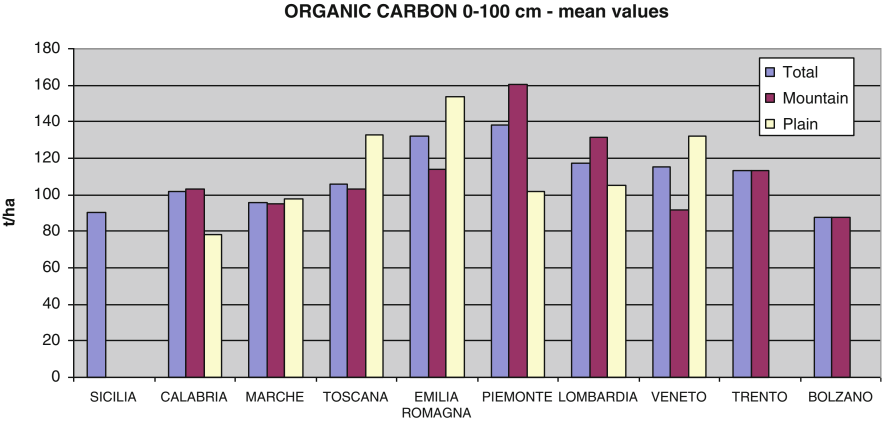

Fig. 18.4 Mean organic carbon values for 0–100 cm

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