Discussion paper: Soil Organic Matter content in Mediterranean regions

(both arable and permanent crops)

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PREPARED FOR THE FIRST MEETING: PADOVA, ITALY 30-31/01/2014

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Index

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1. Scope of the discussion of the Focus Group

DG AGRI has formulated a couple of starting questions in order to focus discussions in the group: ***How can we improve soil organic matter content in the Mediterranean region in a cost-effective way?*** and ***What new solutions for securing soil functionality and soil fertility can be proposed in this regard?*** are the topics to be addressed and discussed by the Focus Group 5.

2. Key functions of soil organic matter

Soil organic matter (SOM) plays a number of key roles in terrestrial ecosystems and agroecosystems, as related to the three components of soil quality and fertility. At a chemical point of view, SOM largely determines, together with clay minerals, the cation exchange (and anion retention) capacity of soil, pH buffering capacity and the retention of inorganic or organic pollutants or toxic elements. At a physical point of view, SOM is crucial in determining soil structure and thereby ultimately controlling soil erosion, water infiltration and holding capacity, habitat provision for plant roots and soil organisms. At a biological point of view, SOM is a primary source of energy for soil microorganisms and thus the whole soil food web, as well as a source of major nutrients, most notably nitrogen, phosphorus and sulfur for plants and the soil biota. Soil organic matter therefore influences a number of ecosystem services (MEA, 2005), such as primary production (and provision of food, fibers…), soil formation (soils being one of the largest reservoirs of biodiversity), biogeochemical cycles and the regulation of water quality and climate. At a global point of view, soils are a major reservoir of carbon (C) in terrestrial ecosystems, the carbon stored in SOM containing more than three times as much C as either the atmosphere or terrestrial vegetation. Soil organic matter can thus play a major role in mitigating climate change but, on the other hand, the decline of its content as a consequence of changes in land use or agricultural practices can substantially contribute to emissions of $C\text{-}CO_2$ to the atmosphere. Yet, according to Schmidt *et al.* (2011), it remains largely unknown why some SOM can persist for millennia whereas other pools of SOM can readily decompose. Such uncertainties limit our ability to predict how soils will respond to global changes. Recent analytical and experimental advances have demonstrated that, contrary to common knowledge, the molecular structure alone does not control SOM stability, which is predominantly controlled by environmental and biological drivers (Schmidt *et al.* 2011). A challenge for the management of rural landscapes and agroecosystems at farm or plot scale is to achieve adequate agricultural production, in terms of both yield and quality of the harvested products, with minimal impact on the environment. This requires trade-offs between the above-mentioned ecosystem services or the various functions of soil organic matter (SOM). For instance, C sequestration in soils occurs at the expense of decomposition and mineralisation of SOM, the latter resulting in the provision of nutrients. The soils with the highest SOM contents are frequently poorly fertile soils in which the mineralisation of SOM is impaired because of the cold climate or because of acidic or waterlogged soil conditions. Nevertheless, too low contents of SOM are undesirable for most soil functions. However, it is not just a matter of content. The location and quality of the SOM should also be taken into account, as well as other key components of soil quality that are strongly determining the fate of SOM, such as the biological properties of soils. Adequate sets of indicators and *ad hoc* guidelines are urgently needed to make substantial progress in the understanding and management of SOM. The review by Lal (2009) summarizes the various strategies that can be implemented in order to preserve or increase the content of SOM in soils. These consist in increasing the inputs of C or in decreasing the losses, with in either case, several conventional and more novel options. Two types of inputs can be distinguished: the plant residues derived from the biomass grown onsite, and various types of biosolids that are most often exogenous materials, including of urban origin. Three types of losses of SOM can be addressed, that are related to decomposition, leaching and erosion.

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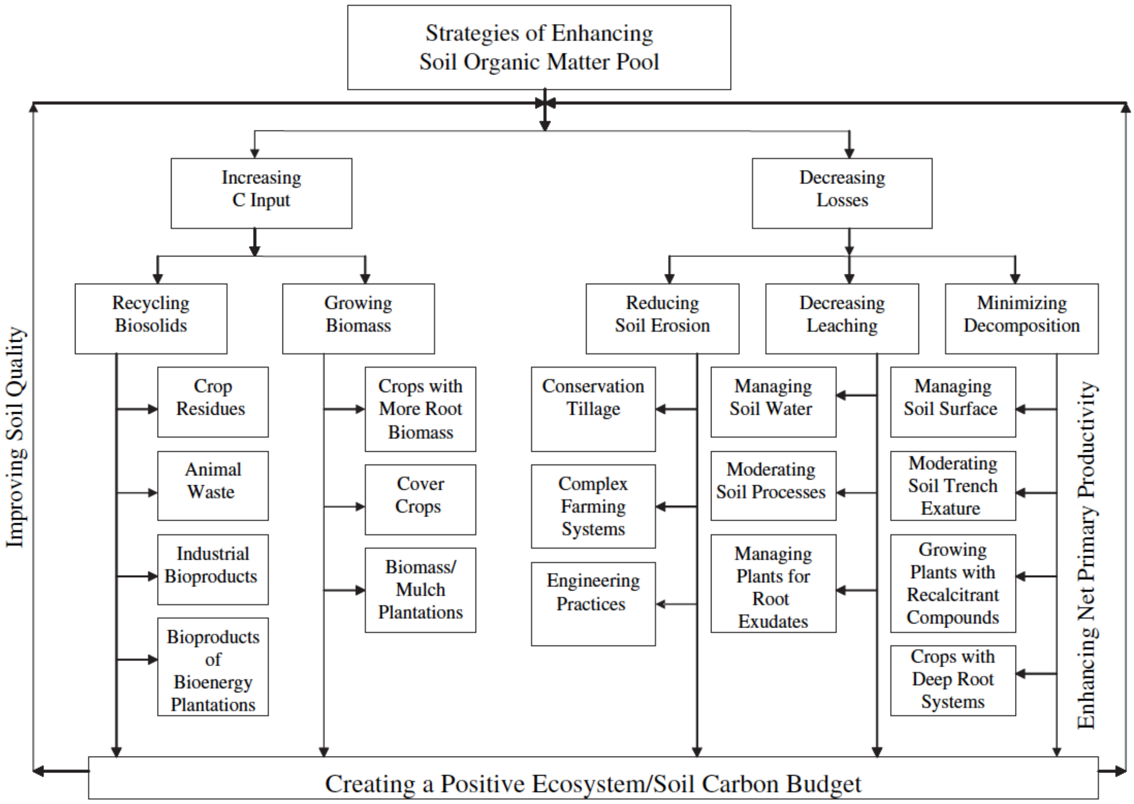
Figure 1. Strategies for enhancing or preserving the organic matter content of soils (Lal, 2009).



3. Background information about SOM in Mediterranean regions and preliminary questions

There is clear evidence of a decline in SOM contents in many soils as a consequence of the unprecedented expansion and intensification of agriculture during the 20th century (Lal, 2009). This decline in SOM content is a threat for the sustainability of agricultural production systems, because SOM is a major component of soil fertility and quality. The official Communication 'Towards a Thematic Strategy for Soil Protection' (CEC, 2002), adopted in April 2002, has identified eight main threats to soils, and considered declining SOM as one of the most serious processes of soil degradation, especially in southern Europe.

As stressed by Jones *et al.* (2003) there was, and still is, an increasing need for accurate information on the SOM content in soils at European, national or regional level. This has been the result of increasing concern about environmental problems such as soil degradation, desertification, erosion, particularly in the Mediterranean regions of Europe and, at the global level, the impact of climate change. Jones *et al.* (2003) indicated that the main objective in producing the Map of organic C (OC) content of European soils displayed in Figure 2 was to identify and to secure an existing information base for OC and SOM contents of European soils at time t_0, i.e. to define a baseline (background) or reference level against which to monitor future trends. This Map was published as S.P.I.04.72 in ISO B1 format, showing the distribution of calculated (modelled) OC contents in topsoils (0-30cm) in Europe. Details about the assumptions made for the purpose of such calculations are discussed by Jones *et al.* (2003) and Zdruli *et al.* (2004). This map shows that the **Mediterranean regions of Europe exhibit distinctively smaller values of OC than those of other regions, with substantial areas showing very low OC (≤1%)** or low OC (≤2%).

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The corresponding proportions have been calculated for various Mediterranean countries (Table 1) and indicate that about 75% of the whole land surface area of Southern Europe fall under these categories. N.B.: such values stand for all land uses together; it would be valuable to get these for agricultural soils.

Figure 2. Map of topsoil organic carbon (OC) content in topsoils (0-30 cm) of Europe (Jones *et al.* 2003). Note that the scale stands only for the mapped European countries.

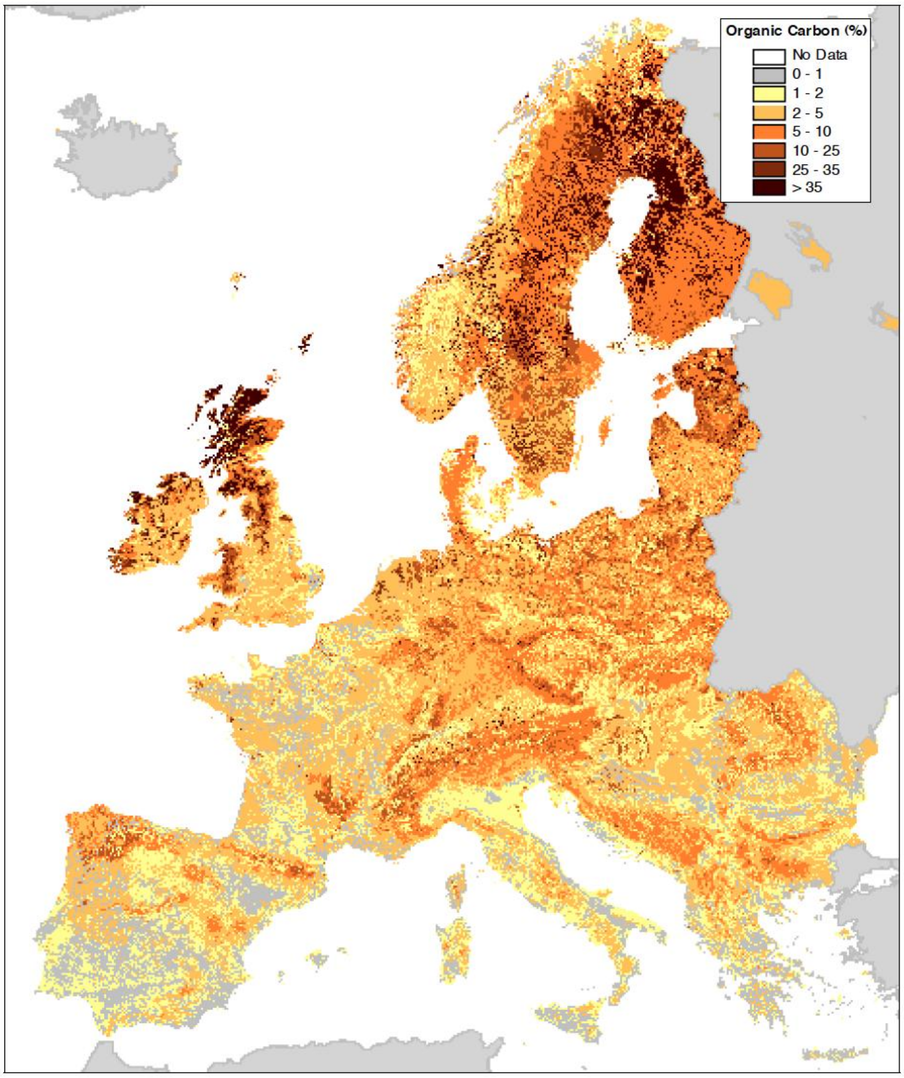

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Table 1. Organic carbon (OC) content in Mediterranean regions of Southern Europe (Zdruli *et al.* 2004). Proportions of total (i.e. not only agricultural) land with very low to low OC (≤2%) and medium to high OC (>2%).

	Total land area	V low to Low	OC<=2%	Medium to High	OC>2%
Country	**km2**	**Km2**	**%**	**km2**	**%**
Albania	28,704,567	21,575,076	75.2	6,788,233	23.6
Bosnia	51,524,030	34,453,723	66.9	16,898,412	32.8
Croatia	56,191,096	28,030,731	49.9	26,903,652	47.9
France (S of 45°N)	196,550,777	116,603,968	59.3	78,371,704	39.9
Greece	133,007,789	126,841,043	95.4	4,868,798	3.7
Italy	300,453,890	259,601,949	86.4	37,341,722	12.4
Montenegro	13,792,171	7,012,719	50.8	6,531,899	47.4
Portugal	89,335,536	51,026,010	57.1	37,944,766	42.5
Slovenia	20,235,843	11,615,170	57.4	8,375,443	41.4
Spain	498,914,695	378,630,678	75.9	117,451,853	23.5
Southern Europe	**1,388,710,394**	**1,035,391,069**	**74.6**	**341,476,480**	**24.6**

3.1 What are the peculiarities of Mediterranean regions contributing to explain their low soil organic matter contents ?

Soil organic matter content is governed by both natural and human factors. These are listed below, highlighting how Mediterranean regions contrast with Northern Europe.

Warm climate and future warming - drought and increasing irregularity in rainfall

Mediterranean regions of Europe are best defined by their distinct climate, with cool humid winters and warm dry summers. This entails higher soil temperatures than in Northern Europe, with an expected negative impact on SOM content as elevated temperatures are known to accelerate SOM decay rate. The quantitative effect of elevated temperatures on SOM is subject for debate, given the large discrepancy among studies in laboratory as well as field conditions. This is of concern in the context of global warming. In addition, most of the current models diverge considerably at high temperatures that are rather common in Mediterranean hot summers. Another typical feature of the Mediterranean climate of Southern Europe is its irregular pattern of rainfall distribution both within a year (about 80 percent falling from October to April) and between years, as well as the high intensity of violent storms. The decay of SOM may thus be accelerated when warm and wet conditions (favouring microbial activities involved in the mineralisation of SOM) prevail such as in spring and autumn, while it may be inhibited by summer drought. Further losses of SOM may be caused by erosion as promoted by the frequent violent storms.

Topography and soil types as related to the parent material

From the geomorphological point of view, the landscape of Mediterranean regions is very dissected, generally rugged and thus prone to erosion. This is further favoured by the incomplete coverage of the soil by the vegetation as a consequence of drought or land uses (e.g. vineyards). Geologically, limestone and calcareous rocks interbedded with shale, siltstones, sandstones, and claystones dominate Southern Europe, while acid and igneous rocks are present as well. Soils are thus diverse, shallow on slopes, often associated with rock outcrops, but deep and fertile in the valleys, where most of the crops are grown. Adequate soil fertility is essential to ensure the most effective use of the limited amounts of plant-available water.

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Calcareous soils with neutral to slightly alkaline pH values are more abundant than in Northern Europe. Such properties rather result in a faster decay of SOM.The presence of inorganic C (carbonates) in such soils makes it more complex to properly assess their SOM content and also the CO_2 emissions deriving from the mineralisation of SOM.

Land use and agriculture

Shifting land use from forest, typical Mediterranean bush ('garrigues' or 'maquis') or grasslands, where topsoil OC content is typically high, to arable land is expected to result in a substantial decline of SOM, as shown in many other environments. Contrary to Northern Europe, agriculture in Mediterranean regions is dominated by fruit trees, citrus, olives, vines, and cereals, most notably wheat. Grasslands and associated stock rearing are of limited extent, so the accumulation of SOM associated with such land uses is severely restricted. The recent detailed maps of OC produced in France clearly show extremely low values, below 1% or even 0.5%, under orchards and vineyards of Mediterranean regions, as well as croplands of Southern France, which are thus of particular concern (Meersmans *et al*. 2012). This study has shown that, at a national level, orchards and vineyards contain an average stock of 3.2 kg C m^{-2}, while croplands contain 5.6, grasslands 8.6 and forests 9.4 kg C m^{-2}. The issue of low OC is thus of particular concern in perennial systems such as orchards and vineyards, which play a more important role in Southern than in Northern Europe. Other relevant features to be accounted for are the social organizations of farmers and other stakeholders, especially those involved in the supply of the various sources of exogenous forms of OC, as well as extension services. In Southern France for instance, many wine growers are organized in cooperatives, which favour exchanges of know-how on agricultural techniques. This is not the case for other types of agricultural productions in the same regions. When intending to implement innovations, e.g. agroecological techniques, one needs to account for the existing structure of supply and production chains (Fares *et al*. 2012).

Degradation of soil and land, including forest fires

Besides changes of land use and agricultural practices, there are other drivers of SOM decline, many of which stem from human activity. Overgrazing with high stocking rates is one of these. Soil erosion by water and wind, as well as leaching are other important causes of SOM losses. In addition, wildfires, which are rather common in Mediterranean regions, can also have a negative impact on SOM, but they normally affect forests and rangelands and are thus of limited concern in cultivated agroecosystems. Erosion is responsible for the removal of soil particles particularly from the topsoil, where the greatest concentration of SOM is usually found in soil profiles. This can have a devastating impact on the overall SOM contents. Leaching and runoff of soil nutrients and organic compounds can be a problem, especially with heavy rainfall or excess irrigation. The recent meta-analysis of Maetens *et al*. (2012) showed that bare soils, vineyards and orchards in Europe are prone to high mean soil losses (10-20 Mg ha^{-1} yr^{-1}), while cropland and fallow show smaller values (6.5 and 5.8 Mg ha^{-1} yr^{-1}). This study reveals that the annual soil losses in the Mediterranean regions of Europe is less than in temperate zones, due to the more abundant stony or clayey soils having a low erodibility. Annual runoff coefficient in the pan-Mediterranean was higher than in temperate zones. Salinity and acidity can also have devastating effects on the quality and quantity of SOM.

3.2 How to assess properly soil organic matter content and quality ?

In their report on mapping of OC content in European topsoils, Jones *et al*. (2003) stressed that in most cases, SOM was measured as soil OC, and, if necessary, the values converted to OM content using a standard conversion ratio OC:OM of 1:1.72. This conversion is considered to be satisfactory for providing data on SOM, given OC measurements in topsoils, for input to broad-scale modelling and policy-making processes. In some cases the more approximate ratio 1:1.7 is used. Jones *et al*. (2003) cautioned that care is needed when inverting the ratio and converting OM to OC, because determining OM by loss on ignition can lead to an overestimation of OC. Therefore, they advocated the adoption of a standard procedure for determining OC for future sampling programmes. Contents of OC have been measured systematically in some European countries, mostly in Northern Europe, including France and its Mediterranean areas (Meersmans *et al*. 2012). France and Italy have large data sets on OC content in soils, whereas most other Mediterranean countries of Europe have only limited data, or data from field surveys that are either insufficiently georeferenced or not accessible outside the country of origin. This is a serious obstacle to using them for defining baseline OC status at European level or for regions of Europe (Jones *et al*. 2003 ; Zdruli *et al*. 2004). In addition, there are a number of other practical issues related to assessing SOM values, both in sampling and in analysis , as listed below.

Spatial variability and depth of sampling

Spatial heterogeneity of soil properties, including SOM content, is the rule at various scales and is generally expected by most soil and earth scientists, while it is often underestimated by agronomists. While vertical gradients are well known, lateral variability of SOM at a metric or sub-metric scale is rather common in soils, including those of agroecosystems. Such vertical and lateral heterogeneities should be taken into account when designing the sampling strategies. This is especially relevant when assessing temporal changes or comparing agricultural practices, e.g. no-till *versus* tilled systems (Balesdent *et al*. 2000).

Accounting for inorganic C (carbonates)

Many soils in Mediterranean regions of Europe are developed on calcareous parent material and still contain large amounts of carbonates, i.e. inorganic C. Care must thus be taken depending on the analytical soil testing method used in order not to overestimate the actual content of OC. For instance, OC is currently often determined by elemental (CHN) analysers, which provides direct measurement of the total C content of the soil and requires a separate analysis of the inorganic C content, in order to ultimately determine the OC content by difference. This can be a source of inaccurate determination of OC in highly calcareous soils.

Alternative techniques (incl. in situ measurements) versus conventional soil testing

Conventional methods of determination of SOM content in soils are tedious and rather expensive. Alternatively, Near Infrared Recflectance Spectroscopy (NIRS) or Mid Infrared Recflectance Spectroscopy (MIRS) have recently proved in many soil types including those commonly found in Mediterranean regions that OC content is accurately predicted, especially in the lower range (e.g. Grinand *et al*. 2012). The use of portable devices even enables a direct measurement in situ under field conditions, which provide unique opportunities to better assess the spatial heterogeneities of SOM. At present such techniques are not directly used by farmers, but they may be developed for usage beyond research organizations.

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3.3 What are the ultimate targets in terms of soil functions and ecosystem services ?

When raising the question of enhancing the SOM content of soils of Mediterranean regions, one should first of all figure out what are the targeted benefits in terms of soil functions or ecosystem services. Some of these issues are briefly discussed below.

Stocks of soil organic matter or soil carbon

Should the primary goal be increasing C sequestration in soils, then extending the assessment beyond the topsoil is essential, while for reducing erosion or improving soil structure, information on topsoil SOM may be enough. In addition, measurement of bulk soil density is needed for evaluating stocks of SOM as required when addressing C sequestration.

Quality of soil organic matter and soil quality at large

Besides the content of SOM in soils, its quality is of utmost ecological and agroecological relevance. Soil organic matter comprises a broad range of pools, which are characterized by very different decomposition kinetics (with turnover rates from hours to millennia) or recalcitrance. Particle size fractionation and the use of stable C isotopes have been extremely helpful to increase our understanding of these various pools. Recent advances have shown however that the fate of SOM cannot simply be deduced from its bulk chemical composition, although the initial decomposition rate of plant residues correlates broadly with properties such as the nitrogen content or the fraction operationally defined as 'lignin' (Schmidt *et al.* 2011). While the molecular structure of SOM has long been thought to determine long-term decomposition rates, molecules predicted to persist for long in soils (such as lignins or plant lipids) have been shown to turn over more rapidly than the bulk of SOM and other potentially labile compounds, such as sugars, have been shown to persist for up to decades. The local micro-environment of these molecules can protect them against decomposition. Similarly, fire-derived organic matter (also called char, black C or pyrolysed C) is found in many soils and is not as stable in soil as expected, in spite of its fused aromatic ring structures, and it has been even observed to decompose faster than the remaining bulk organic matter (Schmidt *et al.* 2011). Nevertheless, indices of the quality and potential turnover rates of SOM pools add much value to the sole knowledge of the OC content of a soil. The decomposition of SOM is also largely being controlled by numerous physical/chemical protection mechanisms and by the nature and activity of soil microorganisms and fauna. Therefore, beyond SOM content and quality, a broader understanding of soil quality, in all its dimensions – biological, chemical and physical – is definitely at stake.

Flux of released nutrients and soil fertility

The nutrient content of SOM and the elemental ratios (stoichiometry of C/N/P/S) are other key properties that determine the fate of OC in soils, as these nutrients alter the activity of soil organisms that all differ in C, N, P and S requirements along the soil food web. This has been well known and accounted for by agronomists for many years in the case of the C/N ratio. However, other elemental ratios are equally important. In addition, the rate of release of such nutrients is crucial to soil fertility and plant nutrition, especially in the context of decreasing inorganic fertilizer inputs as occurs in present-day European agriculture. Improving soil fertility however, may not be systematically relevant as an ultimate goal. Once again, the concept of soil quality seems appropriate to pursue, as it is a less restrictive concept than soil fertility. In many wine growing areas, it is observed that the best quality wines (often linked with small yields) are produced in vineyards corresponding to poorly fertile soils. Here, the concept of land suitability is relevant: the degree of fitness of land (soil + landform + [micro]climate) for a specific use.

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4. How can we improve soil organic matter content in the Mediterranean region in a cost-effective way ? What new solutions for securing soil functionality and soil fertility can be proposed in this regard ?

4.1. Using exogenous sources of organic matter

Many field experiments, including long term trials, have consistently demonstrated the ability of various types of exogenous sources of OC to maintain or increase SOM content, while in contrast the use of inorganic fertilizers resulted in a decrease of SOM. The oldest long-term studies have been conducted mostly with animal manure, but more diverse sources have been tested since then, including various types of organic wastes derived from the agro-industry or bio-solids from urban origin (food wastes and sewage sludge), more or less composted with or without added plant materials. These sources differ in quality and availability, and pose the question of C fluxes across landscapes or regions. It would be extremely helpful to make an inventory of OC resources in each sub-region of the Mediterranean countries of Europe, which could be presented as in the following table (Table 2).

Table 2. Inventory of sources of exogenous OC in region X of Mediterranean countries of Europe

Type of OC source	OC content	Nutrient content	C/N	Other properties	Estimated resource size	Market price

Quality of sources

The particle size, elemental ratios and biochemical composition of exogenous OC sources partly determine the fate of the C and nutrients that they contain once applied in various environmental conditions. These properties vary considerably among the different types of exogenous organic sources. The conventional exogenous sources, farmyard manure and slurries, are quite rich in nutrients compared with rather novel, recently developed products such as biochar or wood chips, which are essentially composed of C. They affect rather differently the various components of soil quality and fertility, besides being a more or less stable source of OC. Side-effects should also be accounted for, either negative such as the micropollutant content of urban bio-solids, or positive such as the increased nutrient-retention capacity provided by biochars.

Availability of sources

At the European level, animal manures and slurries represent considerable amounts of C, compared to bio-solids of agro-industrial or urban origin and recently developed products such as biochar. This should be borne in mind as the latter will hardly be available in sufficient amounts to address the regional issue of maintaining or increasing SOM content in Mediterranean regions. In addition, even for the most abundant sources such as animal wastes, a major limitation is the cost of their transportation over long distance, given the high rates of application required to maintain SOM in topsoils. This is an issue in the many regions that rely little on animal-based farming systems, given the long-lasting trend of agricultural specialization of rural regions in Europe. Nowadays in many Mediterranean regions, vast areas are specialized either in cereal crop production or in vineyards and orchards with hardly any animals at all. Hence, the availability of animal manures and slurries is frequently limited.

Fluxes of carbon across landscapes and regions

The above-mentioned interregional specialization of European agriculture raises the question of fluxes of C between regions that produce excessive amounts of animal wastes due to a large concentration of piggeries (e.g. Brittany in France, Denmark and The Netherlands in Northern Europe, or Catalonia in Spain) and neighbouring regions that are lacking such exogenous sources of OC. The cost of transportation is however a major and increasing limitation. This further highlights the need to redesign the agricultural landscapes of Europe, in an attempt to better integrate animal and plant productions at a local scale.

4.2. Minimising the use of practices known to accelerate the decay of soil organic matter (especially ploughing)

Besides the strategy of increasing the input of OC (Figure 1), an alternative or complementary strategy is reducing OC losses, e.g. via the promotion of no-till practices, of techniques limiting soil erosion by improved, year-round soil coverage with crops or crop residues, or via minimal offtake of plant products (e.g. straw in cereals).

Minimal or no tillage

Numerous studies have confirmed the detrimental effect of cultivation and tillage, especially deep ploughing, on SOM content, as reviewed by Balesdent *et al.* (2000). In Mediterranean soils some long term experiments have shown that no-tillage practices can result in larger topsoil SOM content than tilled systems, e.g. in Spain (Álvaro-Fuentes *et al.* 2008). No-tillage or minimal tillage and soil conservation techniques should thus be considered as interesting alternatives in annual crops. In perennial crops, using a grass cover in the inter-rows of trees and vines may be better suited than tillage, although it raises the question of the competition for water in rainfed systems of Mediterranean regions.

Soil coverage by plant material (cover crops, intercrops, grass cover, etc.)

This is of particular concern in orchards and vineyards as such perennial crops only partly cover the soil, making the inter-rows prone to accelerating runoff, water-erosion and ultimately losses of topsoil SOM. In the absence of a dead (mulch) or live (e.g. grass) cover (or frequent tillage of the topsoil), many soils with low OC content rapidly form a surface crust. This limits considerably the infiltration even when the topsoil is dry, which ultimately results in runoff and erosion when heavy rains occur, a typical feature of the Mediterranean climate. This further accelerates the decline of SOM in the topsoil. Another negative feedback of the Mediterranean climate is that, in the absence of irrigation, drought can result in scant coverage of the soil by the plants. In arable land uses based on summer crops, soils are exposed to erosion, runoff and leaching during a substantial part of the year, which may coincide with heavy rains. Making use of cover crops, relay crops or other intercropping systems may minimize such potential losses of OC, while providing additional inputs of plant litter and thus organic matter to the soil.

Management of plant litter resources (both above- and below-ground)

In many arable systems, besides grains, other parts of the plants may be harvested and contribute to organic matter export instead of being incorporated back in the soil. This is typically the case of straws in many cereal-based systems. Besides avoiding such practices that contribute to additional OC losses, the choice of crops or genotypes, crop rotations and associations (cover crops, relay crops or intercrops) are part of the options to increase the input of OC, as further discussed below.

4.3. Implementing agro-ecological approaches in order to make better use of ecological processes and drivers of the fate of SOM

Besides the previous conventional approaches that rely on practices that have been used for decades in agroecosystems, in which the farmer is engineering the system, alternative options are based on improving ecological processes within the agroecosystems, in order to favour the functions and activities of soil biota that ultimately enable maintaining or increasing the SOM content; either the decomposers directly, i.e. soil microbial communities or the so-called ecosystem engineers such as earthworms (and other macrofauna) and plants.

Managing soil microbial communities

Soil microbial communities are extremely diverse and complex and play a key role in the fate of SOM. However, there are few reliable indicators of microbial communities that can be used for evaluating their potential impacts on SOM. Microbial biomass is one of the few quantitative indicators, often positively correlated with SOM, but there is a lack of reference guidelines to properly use it as an indicator. Dequiedt *et al.* (2011) have shown at the country scale in France that the microbial biomass of soils of orchards and vineyards, as determined by molecular techniques (DNA extraction), is significantly lower than in arable land, grasslands and forests. Other commonly used indicators rely on measurements of a range of potential enzymatic activities as well as potential respiration, for which *ad hoc* reference guidelines are lacking as well. Batteries of biological indicators and multiparametric indices are being developed (Bastida *et al.* 2008). In addition, novel indicators have been implemented, based on analysis of the nematofaunal community, which comprises functional groups involved in the predation (and thus control) of bacterial or fungal communities. These have been used by Coll *et al.* (2011) to appraise the quality of vineyard soils in the Mediterranean part of France. However, as long as proper indicators are not available, it is difficult to evaluate the potential use of techniques designed for manipulating soil microbial communities. The use of microbial inoculants remains questionable in this context, and indirect manipulation of the autochthonous microorganisms maybe more efficient.

Managing soil macrofauna (and mesofauna)

Soil macrofauna and mesofauna comprise a broad range of organisms that are involved in either the incorporation of plant residues in soils, or in the alteration in size and composition of the various sources of OC that they manipulate (e.g. a number of small invertebrates of the mesofauna) or ingest (earthworms). Tillage has been consistently shown to reduce the size of the earthworm communities, while soil conservation techniques and an abundant plant cover usually have a positive effect.

Using deeper rooted systems or plants that allocate more carbon to top- and subsoil

Breeding plants that allocate more C to their root system may appear as an interesting means of increasing the input of C in both the top- and subsoil with local resources of OC (Kell 2011). The development of perennial cereals may contribute to fulfilling such a goal. In addition to this, plant residues in general are a major source of OC to be better used for maintaining or increasing the SOM content of soils.

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funded by European Commission