7 Soil Functions and Ecological Services

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7.1 Introduction

Soil functions are closely related to soil ecosystem services, defined as the complex of actions sustained by soils to guarantee life on the earth. Briefly, they can be summarized as: biodiversity and habitat, nutrient cycling, water regulation, filtering and buffering, physical stability and support (European Atlas of Soil Biodiversity 2010). As the majority of soil functions and ecological services are associated with the presence of a complex system of organisms in soils, in this chapter we will mainly deal with the management and diversity of biotic resources in soils and environments typical of the Italian landscapes.

According to the National Biodiversity Strategy (MATTM 2010), the concept of "eco-region" as ecological zones identified by different climate, vegetation and land use were identified and mapped for the whole Italy (Blasi and Michetti 2005). For example, by considering only vegetation of the Mediterranean area, this study recognized 25,000 species of plants, representing more than 10 % of all planet plants, compared with the 6,000 species living in the rest of Europe.

Another important phenomenon concerns endemisms: over 80 % of European plant endemisms are in this area. The same is true for some types of arthropods (collembola or spiders). Soil microbial biodiversity is the product of the interaction between the "ecological" component and "pedodiversity", recognized as the genetic differentiation of soils and horizons within landscapes.

The interaction of ecoregions with the distribution of soils and soilscapes was analysed by comparing soil information with land use, climate, pedoclimate and vegetation (forests and natural areas or areas in the process of naturalization) and by defining geographical levels in Soil Regions (Costantini et al. 1999) and Soil Systems (Costantini et al. Chap. 6).

Soil variability is represented by about 1,400 different Soil Typological Units (STU) all over Italy. Twenty-two reference groups and 146 types are represented at the first qualifier level in relation to soil diagnostic horizons, materials and properties and concerning only the main soil types in the Soil System Map units.

The national level of Soil Systems, developed within the national programme "Soil map of Italy at 1:250,000 scale", is still under construction; likewise, the national archive and database of soil physical characteristics and qualities (soil hydrology, fertility and biodiversity) linked to STU.

This study phase allows us to make a series of important assertions relative to the geographical and typological taxonomic distribution of the relationships between microbial biodiversity and pedodiversity, which will be reported in this chapter in the form of case studies. However, a single national thematic mapping of biological fertility and microbiological-based indicators till now is not available.

7.1.1 Microbial Biodiversity and Soil Functions

Soil biodiversity is a general term used to describe the variety of life below ground. The concept is conventionally used in a genetic sense and denotes the number of distinct species (richness) in a system and their proportional abundance (evenness), but may be extended to encompass phenotypic, functional, structural or trophic diversity.

On a microbial scale, the total below-ground biomass generally equals or exceeds the above-ground biomass,

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while below-ground soil biodiversity always exceeds that on the associated surface by orders of magnitude. A handful of grassland soil will typically support tens of thousands of genetically distinct prokaryotes (bacteria, archaea) and hundreds of eukaryotic species across many taxonomic groups. For instance, agricultural soil usually contains in the order of 3,000 kg of living biomass (fresh weight) per hectare, and we found between 55 and 98 % of the Earth's total biodiversity in soil.

At this level, the soil biota plays a vital role in delivering key ecosystem goods and services, and through nutrient cycling, decomposition and energy flow, it is both directly and indirectly responsible for many important functions in soil. And yet soil organisms have had a negligible influence on the development of contemporary ecological theories (Wardle and Giller 1996).

Soil organisms are the most important factor in soil formation as both their trophic and non-trophic effects define the difference between soils and non-soils (Jones et al. 1997). Through their non-trophic activities, soil organisms physically modify, maintain or create new habitats for other organisms, which may in turn lead to increased species diversity. Close interactions between microorganisms and other soil-forming factors lead to important biological processes with a major impact on the global carbon cycle as soil stocks carbon mainly in the form of soil organic matter and releases carbon in the form of carbon dioxide (CO_2) formed during the decomposition of soil organic matter (Schils et al. 2008; Lal 2004).

Microbes also play an essential role in soil water regulation and particle aggregation. Actually, soil structure formation is mediated by physicochemical processes and by the activity of living organisms such as bacteria, fungi, meso- and macrofauna and plant roots; while decomposing organic material, soil microorganisms excrete substances that can act as binding agents between soil particles and facilitate the formation of soil aggregates. A sound soil structure facilitates the germination and the establishment of crops, improves the water-holding capacity that can prevent or delay drought and ensures a better infiltration capacity, which prevents waterlogging, as well as improves aeration of the soil. Furthermore, good soil structure offers resistance and resilience to physical degradation, such as erosion and compaction, and helps the movement of organisms in the soil.

Many of the functions performed by soil microorganisms can provide essential services to human society: agricultural production and food processing depend heavily on this "hidden" biodiversity, and plants and animals cannot grow optimally without them. Without soil fertility, management of sustainable agriculture is impossible. A good example of the role of microorganisms in soil fertility and plant nutrition is represented by the fungi and other microorganisms that establish a mutually beneficial symbiosis with the roots of agricultural plants, like the symbiotic microorganisms whose actions directly improve plant growth (for example, root-nodulating bacteria enabling nitrogen fixation in legumes, mycorrhizae, etc.) or the free-living microorganisms that elicit a positive reaction when in intimate proximity with a plant or animal (for example, *azotobacter* by supplying small amounts of nitrogen to plants) or the microorganisms that decompose organic matter and transform mineral nutrients in the soil. Microorganisms are primary agents of nutrient recycling, greenhouse gas emission mitigation, soil structure, nutrient acquisition by plants, etc. Finally, microorganisms provide primary metabolites that act as mediators for the production of commodities and fine chemicals used in agriculture and play a key role in other biotechnological applications, involving bioremediation of polluted sites or restoration of loss of biological fertility caused by genetical erosion of microbial populations.

Soil life can be divided into trophic levels. On the lower trophic level lays the soil microbial population, which degrades plant, animal and microbial bodies as well as serving as a food source for some of the higher levels. For example, soil protozoa consume a big amount of bacteria as well as fungal spores.

The theory that biological diversity and ecosystem stability are based on community stability arises from food-web structures, rather than from the autoecological properties of certain species. In an ecosystem with many energy pathways, changing the number of a single species will have less effect on the other species than in an ecosystem with only a few energy pathways. In this food-web model, the effect of diversity or a sudden alteration of the abundance of one community member can act as a perturbation. Soils with greater levels of biodiversity are more resistant to environmental disturbances and are therefore more resilient.

A healthy soil biota needs an appropriate habitat. Hence, threats to soil such as erosion, contamination, salinization and sealing all serve to threaten soil biodiversity by compromising or destroying the habitat of the soil biota. Management practices that reduce the deposition or persistence of organic matter in soils or bypass biologically mediated nutrient cycling also tend to reduce the size and complexity of soil communities. It is however notable that even polluted or severely disturbed soils still support relatively high levels of microbial diversity at least. Specific groups may be more susceptible to certain pollutants or stresses than others, for example, nitrogen-fixing bacteria that are symbiotic to legumes are particularly sensitive to copper; colonial ants do not tend to prevail in frequently tilled soils due to the repeated disruption of their nests; soil mites are generally a very sturdy group.

In order to understand the soil microbial world and its role in ecosystem functioning, in addition to single organisms also density, diversity and activity of microbial populations, isolated from natural environments, need to be considered. These processes bring about variations in the microbial community structure and diversity in multiple situations and allow the identification of populations preferentially associated with various habitats and different environmental contexts. All these studies provided information about the high dynamic responses of microbial genetic resources under different human or climatic impacts. Microorganisms require only a brief time to reproduce (from hours to days), allowing them to react to pressure and to transfer genetic modification very swiftly at population levels (Van Elsas et al. 2006).

7.2 Soil Organic Matter and Microbial Activity-Related Soil Functions

Soil organic matter is the main nutritional substrate sustaining the development of microorganisms by means of processes capable of influencing community structure. In this paragraph, we will discuss the relationship between different quality and quantity characteristics of soil organic matter and the behaviour of soil microorganisms, focusing, in particular, on examples related to the Italian context.

Organic matter content in soil is adopted as a widespread soil quality indicator since it is correlated with multifarious aspects of productivity and sustainability of agricultural ecosystems and environmental conservation (Smith et al. 2000). In general, high soil organic matter content is held to be advantageous, even if it has been shown to have a negative impact on the environment or productivity within the framework of specific contexts and processes (Sojka and Upchurch 1999). Organic matter not only affects the chemical and biological properties of soil, as it is the main nutritional substrate for the microbial community, but also affects its physical properties. In fact, the sole non-modifiable physical property of soil is texture, whereas structure stability, water retention, colour and thermal capacity are related to the quantity and quality of soil organic matter.

The term soil organic matter embraces all soil organic material including decomposed and decomposing litter, microbial biomass, soluble organic material and stabilized organic matter (such as humus and mineral-bound organic complexes). Such matter is therefore extremely heterogeneous and chemically complex—especially more biochemically stable fraction commonly referred to as humic matter—and is currently a matter of investigation. Although many recent research projects are investigating molecular models facilitating the understanding of both the structure and functioning of soil organic matter as a whole (Schaumann and Thiele-Bruhn 2011), from an operative point of view, humic substances (amorphous dark-brown polymeric compounds with molecular weights ranging from hundreds of Daltons—in the case of fulvic acids—to hundreds of thousands of Daltons—in the case of humic acids) are normally divided in three main fractions on the basis of their solubility in alkali and acids: (1) humic acids (HA), fraction that is soluble in diluted alkali but precipitates for alkaline extract acidification; (2) fulvic acids (FA), humic fraction that remains in solution when the alkaline extract is acidified as it is soluble in both diluted alkali and diluted acids; (3) humin, humic fraction that cannot be extracted from soil by diluted alkali or acids. This approach is still adopted in order to characterize the distribution of these different fractions along the soil profiles or according to different land uses, since humic substances are characterized by intermediate carbon turnover times with respect to more labile fractions, which are more directly involved in soil microbial metabolism.

In Italy, there is a widespread gradual reduction in organic matter content in cultivated soils for multivarious and often interrelated causes. Some of these causes are related to reduced organic matter supplies (separation of animal husbandry and crop farming, non-utilization of crop residues, specialized crop farming, simplified crop rotation, almost exclusive use of inorganic pesticides, etc.), while others are due to increased organic matter mineralization rate (more frequent and deeper tilling, diffusion of irrigation procedures) etc. The entire Mediterranean area is one of the most exposed areas to depletion of agricultural soil fertility due to rapid organic matter mineralization processes. It is known that soil microorganisms making nutrients available to plants are regulated by temperature and moisture and that conditions for organic matter mineralization are ideal in spring and autumn and in irrigated and winter cultivations in areas of Italy where temperatures do not drop below 5 °C (mineralization stops below this temperature).

7.2.1 National and Local Studies on Soil OM Dynamic and C Storage

Two investigations on soil organic carbon (SOC) variations were recently carried out at national level in Italy using different methodological approaches and soil data. The first one (Fantappiè et al. 2011) predicted SOC using multiple linear regression analysis models as a function of climate change along with other landscape parameters for different time lapses all over Italy from 1961 to 2008. Results showed that temperature had the most relevant impact on SOC with an inverse correlation, whereas SOC was directly correlated with precipitations on arable lands and inversely in forests and meadows; from the 1961–1990 to the 1991–2006 period, there was a mean SOC decrease of 0.2, 0.57 and 0.76 dag kg^{-1} for arable lands, forests and meadows, respectively (Fantappiè et al. 2011). The second study (Chiti et al. 2011) calculated the total amount of SOC stock in the top 30 cm of mineral soil layer for the 1995–2005 period on the basis of soil data from the national SIAS project collecting SOC data from local databases using the INSPIRE geographical standard (EU 2007). The SOC stock for the whole cropland category was shown to be 490.0 ± 121.7 Tg of C; arable land and agroforestry represent about 70 % of this category (Chiti et al. 2011). Numerous studies in recent years have examined the most favourable management practices for increasing C storage and preventing soil erosion processes in agricultural soils. Recently, the results of long-term experiments carried out in various experimental farms were collected and published in order to monitor and assess the environmental protection measures imposed by the Common Agricultural Policy (Bazzoffi 2011). In particular, different types of behaviour were observed in case studies in different areas with different Soil Systems.

7.2.2 Case studies on Soil Organic Matter Trends Related to Different Cropping Systems

Case study 1: Mediterranean environment of Apulia in EU Soil Region 62.1 (see Chap. 6), soil system landscape "Stream terraces on alluvial deposits, alluvial lacustrine or glacial fluvial with mixed lithology covered by row crops" (Fig. 7.1).

Very slow soil organic matter–related processes were observed in an alluvial clay loam soil, classified as Grumic Calcic Vertisol (World Reference Base 2007) in south Italy, Foggia (41° 26′ N, 15° 30′ E, 90 m a.s.l.), in an agricultural area cultivated with cereal, leguminous vegetables and industrial horticulture (Fig. 7.2). Thirty-two years after the beginning of the experiment into the effects of different residue management practices on the chemical properties of soils, it was revealed that the mere incorporation of straw and stubble induced only a slight increase in soil organic matter (0.7 % on average) with respect to burning of residue, a common practice in that area (Ventrella et al. 2011). In the same area (41° 27′ N, 15° 30′ E, altitude 79 m above sea level), with a clay loam soil classified as Eutric Vertisol (World Reference Base 2007), it was also shown that crop rotations are not so effective as expected in maintaining or increasing the organic carbon content in soil (Borrelli et al. 2011). In particular, after 16 years from the beginning of the experiment, a decline in SOC was observed in all rotations (continuous wheat, wheat–oats–bare fallow; wheat–chickpea and wheat–wheat–tomato) with the exception of the wheat–wheat–bare fallow rotation where the organic carbon content remained constant.

Case study 2: Central Italy (Tuscany) in EU Soil Region 78.2, soil system landscape "Low hills and aggraded landforms (terraces and alluvial fans), on alluvial, alluvio-lacustrine and glacial fluvial deposits with mixed lithology" (Fig. 7.3).

In an experimental area in a hilly region of central Italy, near Florence, (43.98°N and 11.34°E) with climate characterized by dry summers and cold winters, mean annual rainfall of about 1,024 mm and mean annual temperature of 13.4 °C and on Calcaric Vertic Cambisols (WRB 2007), the effects of crop rotations (continuous maize and a three-year

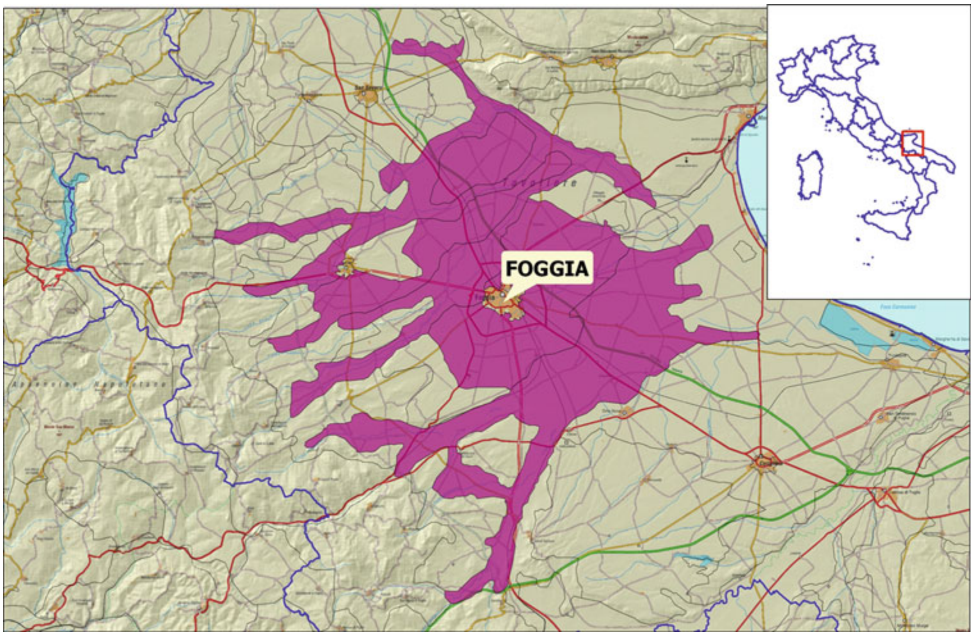

Fig. 7.1 Location of soilscape with Calcic and Eutric Vertisols, Apulia region

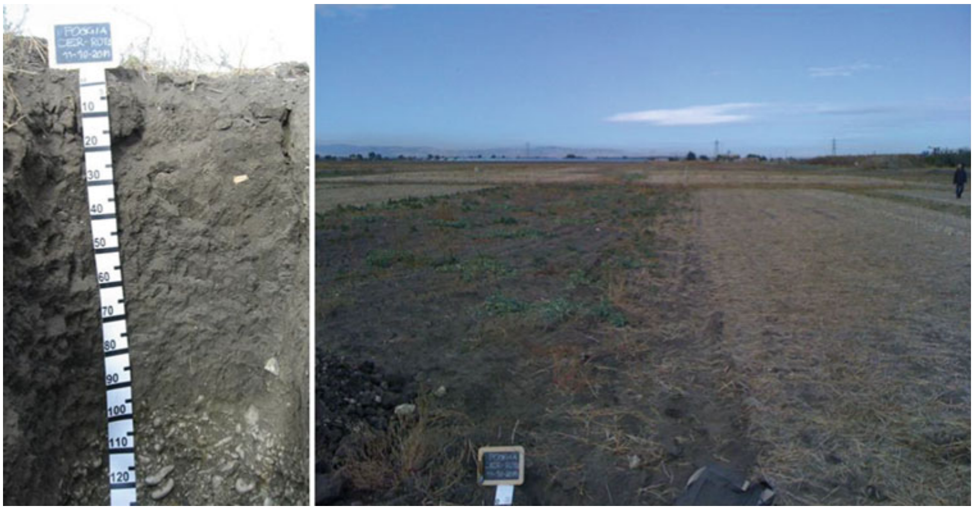

Fig. 7.2 Grumic Calcic Vertisol on alluvial fine deposits flat plain soilscape near Foggia

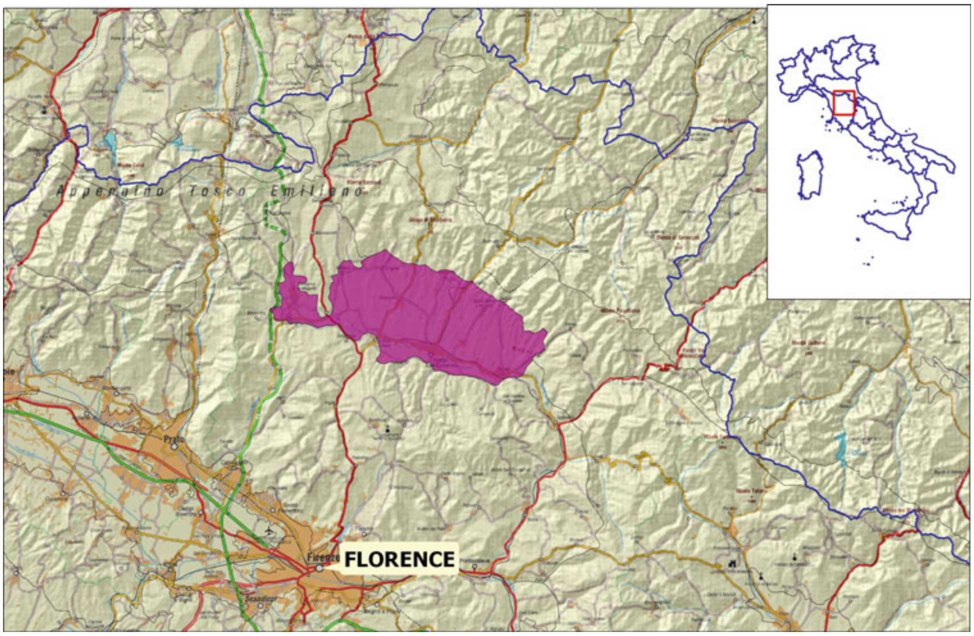

Fig. 7.3 Location of soilscape with Calcaric Vertic Cambisols, Tuscany region

rotation maize–wheat–field bean) on the soil organic carbon content were also negligible.

Moreover, cropping system and tillage (minimum tillage, ripper sub-soiling, conventional deep ploughing and shallow ploughing) did not impact on the relative size (rate) of the soil microbial pool (Cmic/TOC) although there was a significant difference in the metabolic quotients of the two cropping systems considered. The lower values of microbial-specific respiration (qCO_2) under maize monoculture seem to indicate a metabolic equilibrium of microflora, which optimizes its energetic requirements through constant plant inputs, whereas crop rotation probably stimulates metabolic activity by returning different types and amounts of organic substrates to the soil (Borrelli et al. 2011).

7.2.3 SOM and Microbial Activity Under Semi-Arid Mediterranean Climate and Different Land Use Conditions

Case study 3: Mediterranean environment of Sicily in EU Soil Region 62.2, soil system landscape “Low, medium and high hills with medium gradient, with rounded or flat summit, with subparallel to subdentritic drainage pattern on mainly, anhydritic or chalky limestone covered by row crops” (Fig. 7.4).

Correlations between vegetation type and soil characteristics were documented in various Italian environments, especially after afforestation programmes conducted with non-native species. One such programme involved the introduction to Sicily in the 1960s of fast-growing forest

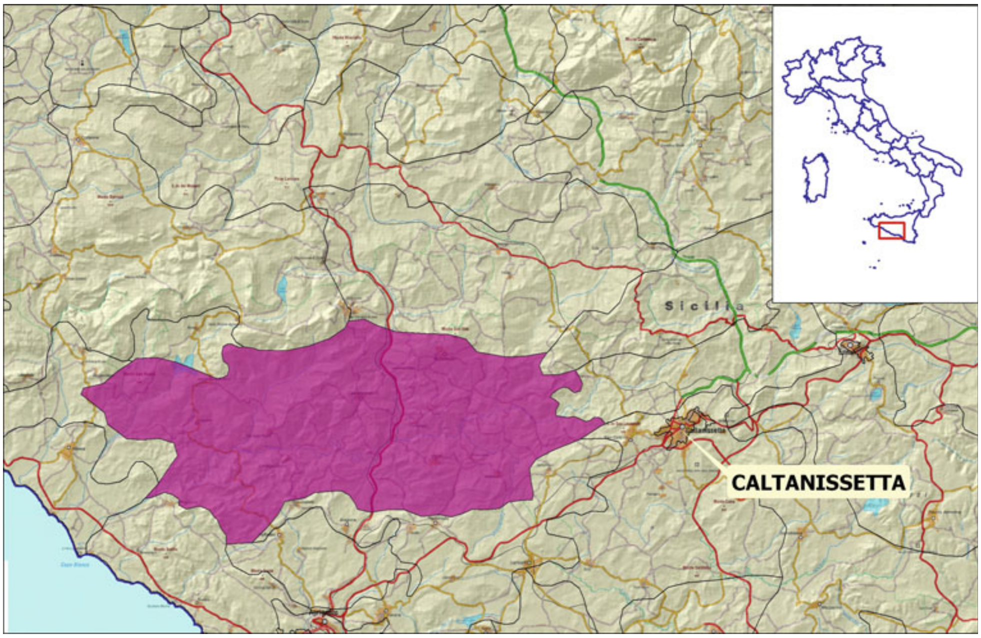

Fig. 7.4 Location of the Soil System in which prevails Xerofluvent–Haploxerert–Calcixerept toposequence (Dell'Abate et al. 2002b), respectively Fluvisols–Calcisols–Vertisols (WRB 2007) in Sicily region 62.2

species suited to warm climates, such as *Eucalyptus spp.*, in order to sustain the development of paper mills as well as help to prevent soil erosion processes. An investigation carried out a posteriori on land suitability for *Eucalyptus camaldulensis* (Fierotti et al. 1995) revealed that many soilscapes are not suitable or marginally suitable because of texture and/or salinity limitations. The limited plant growth and low soil carbon storage, both below the expected values, gave rise to an in-depth investigation of soil microbial activity in a toposequence selected along a morphological transect in that area, a gypsiferous hilly area near Caltanissetta. The toposequence starts from a small valley with alluvio-colluvial soil such as Typic Xerofluvent (profile MG16) or Humic Fluvisols (WRB 2007) and go to the hilltop considering from down to up Vertic Haploxerert (profile MG1 or Eutric Vertisols (WRB 2007), Gypsic Vertic Haploxerert (profile MG22)) or Vertic Calcisols (WRB 2007) and Gypsic Calcixerept (profile MG64, Fig. 7.5) or Gypsic Calcisols (WRB 2007; Dell'Abate et al. 2002b).

The main results obtained showed a sharp drop (approximately 50 %) in carbon content from the surface horizons to the layers below, followed by a gradual decrease along the profiles. A similar trend was revealed for the alkaline extractable fractions of organic matter and soil nitrogen content. A relatively high amount of humified organic matter was found in comparison with total organic carbon content: the humification degree, calculated as the percentage abundance of humic and fulvic fraction in the extractable fraction according to the classic approach based on different solubility in basic or acidic media, was close to 100 % in most samples at all soil depths, indicating the

Fig. 7.5 Gypsic Calcixerept (Gypsic Calcisol, WRB 2007) in hilly soilscapes of central Sicily, on "evaporitic deposits" under *E. Camaldulensis* afforestation

presence of active humification processes in deeper horizons leading to accumulation of humic substances and consequently to stabilization of soil organic matter.

However, the lack of labile organic substrates available for microbial metabolism within the soil ecosystem may indicate potential soil degradation because the functioning of the microbial community could be sustained by mineralization and depletion of more stable fractions, such as humified fractions.

Measurements of soil respiration and microbial biomass activity (Table 7.1) showed trends similar to those of total organic carbon content along the soil profiles, in particular, relatively high values of cumulative respiration in the deeper horizons indicated intensive microbial activity correlated with organic matter content, with C mineralization coefficients ranging from 3.3 to 4.8 % of total organic carbon up to about 100 cm in depth. Higher respiration rates and metabolic quotients were recorded in the deeper horizons of the pedons (all evaluated as not suitable for *E. camaldulensis*), indicating more rapid organic matter turnover than in the surface horizons and a possible stress condition for soil microorganisms.

Other investigations examining benchmark soils in xeric climates in south Italy (Fig. 7.6) also recorded high levels of microbial activity despite the low ratio of Cmic:Corg in deeper horizons (Marinari et al. 2010): the two benchmark Vertisols (Grumic Pellic Vertisol and Eutric Vertisol) were, respectively, located in gypsiferous hilly landscapes in Sicily (the same ones examined in Case study 3) and on a coastal plain with dune bars on littoral deposits and marine sublittoral, alluvial and delta deposits covered by row crops in Lucania (Soil Region 62.1), while the two benchmark Alfisols—a Ultic Haploxeralf (Chromic Luvisol, WRB) on karstic hills and upland plains with a Murge-type doline drainage pattern on mainly limestone covered by row crops (EU Soil Region 72.2) and a Mollic Haploxeralf (Luvic Phaeozem, WRB) on dissected marine terraces and coastal plains in the Rutigliano Mola di Bari areas on mainly anhydritic or chalky limestone covered by olive groves—were located in Apulia (Marinari et al. 2010). The increased values of metabolic quotients in deep horizons reflected the low energy-transforming efficiency of the microbial community, also deduced from the negative response of microbial biomass to a more complex humic acid structure along the profile. In fact, humic acids extracted from the upper horizons of these pedons showed a higher aliphatic character than those extracted from the deeper horizons, which had a higher content of aromatic structures and polysaccharides.

Previously, humic fraction distribution and chemical structural stability were studied (Dell'Abate et al. 2002c) along the soil profile of two Vertisols located in a hilly area of Sicily, a Typic Haploxerert (Grumic Vertisol, Hyposodic, WRB 2007) and a Typic Haploxerert (Grumic Pellic Vertisol, Hyposodic, WRB 2007), respectively. SOM

Table 7.1 Main C fractions and microbial parameters in soils under *E. camaldulensis*

		Cmic	Ccum	qCO_2	K	Corg	Cext	Cha + fa	DH
Typic Xerofluvent (Humic Fluvisol, WRB) MG16	(0–15)	227	551	2.43	3.55	13.5	10.3	9.8	95
	(15–30)	205	279	1.36	6.40	7.1	4.7	5.6	100
	(30–50)	185	301	1.63	5.71	7.3	5.6	5.7	100
	(50–90)	118	253	2.14	6.90	5.3	3.6	4.3	100
Vertic Haploxerert (Eutric Vertisol, WRB) *MG1*	(0–30)	339	599	1.77	5.51	14.3	11.5	11.9	100
	(30–70)	110	307	2.79	6.69	8.8	5.8	4.2	73
	(70–125)	77	226	2.94	8.76	7.0	3.9	2.8	71
Gypsic Vertic Haploxerert (Vertic Calcisol, WRB) *MG22*	(0–20)	315	478	1.52	5.06	17.0	12.3	13.0	100
	(20–50)	60	258	4.30	9.00	7.9	5.3	5.1	97
	(50–80)	170	194	1.14	7.86	4.8	2.3	2.7	100
	(80–95)	47	136	2.89	6.06	4.1	2.0	2.0	98
	(95–110)	48	137	2.85	5.93	3.8	1.5	2.0	100
Gypsic Calcixerept (Gypsic Calcisol, WRB) *MG64*	(0–15)	574	777	1.35	4.61	19.8	13.5	14.5	100
	(15–60)	154	333	2.16	5.68	9.7	5.7	6.3	100
	(60–80)	87	273	3.14	7.34	7.9	5.5	7.2	100
	(80–100)	72	232	3.22	6.11	5.2	2.7	3.2	100

Soil classification according to Soil Taxonomy, in Dell'Abate et al. (2002b), in parenthesis the corresponding WRB classification is reported. *Cmic* microbial biomass carbon, mg C kg^{-1} soil; *Ccum* cumulative respiration, C–CO_2 total production at 32nd day, mg C–CO_2 kg^{-1} soil; qCO_2 metabolic quotient, (mg C-CO_2) (mg Cmic kg^{-1} soil)$^{-1}$ h^{-1} ; *K* rate constant of carbon mineralization; *Corg* total organic carbon, g C kg^{-1} soil; *Cext* total extractable carbon, g C kg^{-1} soil; Cha + fa = humic and fulvic acid carbon g C kg^{-1} soil; *DH* humification degree, mg Cha + fa mg $Cext^{-1}$ 100

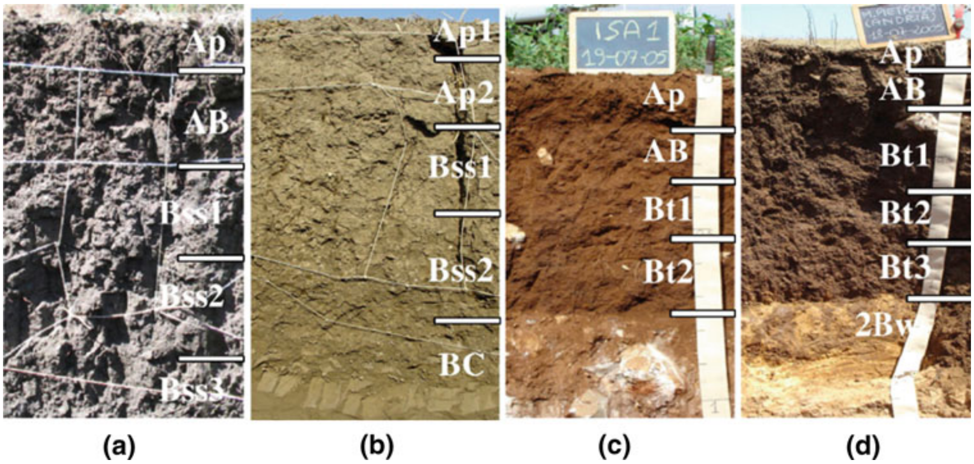

Fig. 7.6 **a** Typic Haploxerert (Grumi Pellic Vertisol, WRB), **b** Xeric Epiaquert (Chromic Vertisol, WRB), **c** Mollic Haploxeralf (Luvic Phaeozem, WRB) and **d** Ultic Haploxeralf (Chromic Luvisol, WRB) located in Sicilian hills (**a**), Basilicata plains (**b**) and Apulia plains (**c**–**d**) (Marinari et al. 2010, photo by C. Dazzi)

characteristics were also related to the different microbial activities and organic carbon turnover times in the two soil profiles (Dell'Abate et al. 2006).

The relationship between the presence of either labile or stabilized organic fractions along the soil profile and the rate of microbial activity in the subsoil, especially in deep horizons, were also observed in a floodplain soil sequence in a Mediterranean environment in Sicily comprising two Vertic Cambisols and a Calcaric Fluvisol (WRB 2007) (Fig. 7.7). In the deep horizons of the Calcaric Fluvisol, the organic matter was entirely in humified forms and the microbial indices indicated metabolic stress due to the harsh organic substrate decomposability, whereas in the two Vertic Cambisols, the microbial activity was almost constant along the soil profile (Dell'Abate et al. 2004).

The occurrence of mineralization activity in subsoil also observed in some Spanish environments was related to the more favourable temperature and water conditions in the deeper horizons in the Mediterranean climate (Rovira and Vallejo 1997).

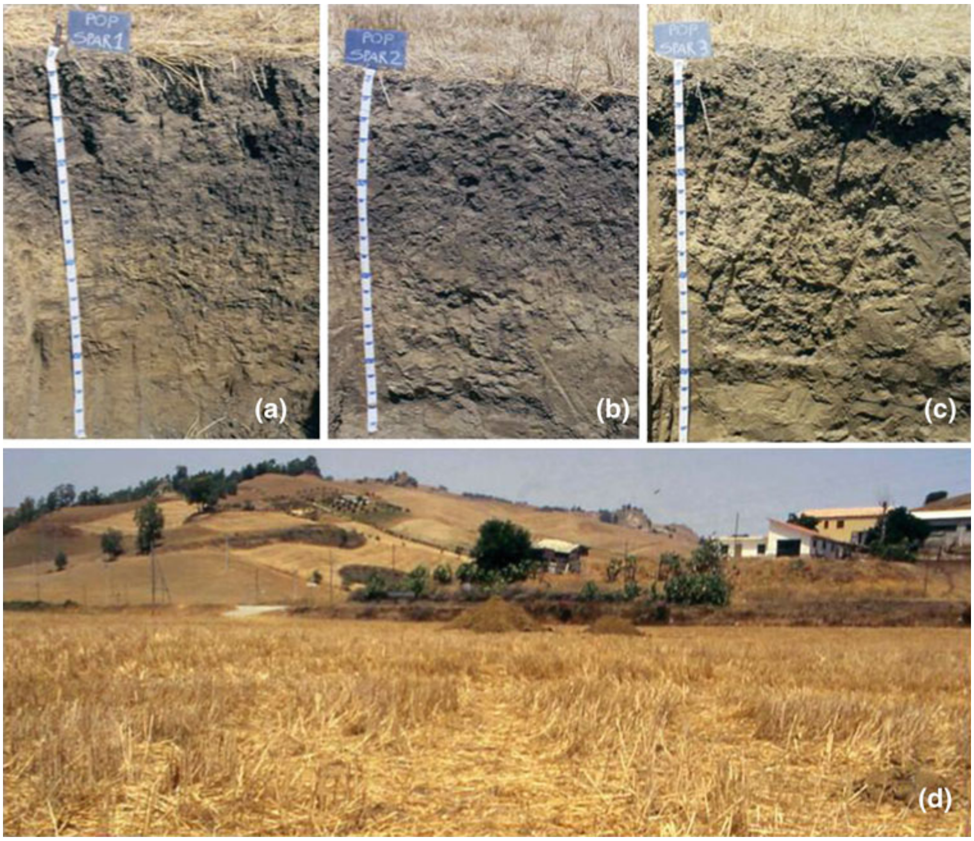

Fig. 7.7 Vertic Cambisol (**a**, **b**), Calcaric Fluvisol (**c**) and soilscape (**d**) of fluvial plain and terraces of Tumarrano Stream (Sparacia, AG, photo by C. Dazzi)

Another investigation (Pinzari et al. 2001) on the influence of plant cover on soil profile evolution was carried out in western Sicily in a homogeneous forested area on Lithic Haploxerolls (Leptic Phaeozems; WRB 2007) 40 years after afforestation with two different plant species, *Pinus halepensis* Miller (ten soil profiles) and *Cedrus atlantica* (Endl) Carrière (ten soil profiles) (Fig. 7.8).

Different types of soil profile evolution were recorded under the two tree stands with the formation of different humus forms—Moder–Mormoder under Cedrus and Mor–Hemimor under Pinus (Dazzi 1996)—along with different C storage in the forest floor—higher under Pinus than Cedrus (Pinzari et al. 2001). Different microbial metabolic activity levels were also recorded in the mineral horizons under the two tree stands; while the decay rate of organic matter (k) calculated by carbon mineralization did not differ significantly, basal respiration, metabolic quotients and microbial biomass carbon all differed. In particular, smaller amounts of microbial biomass sustained higher metabolic activity under the Pinus trees, indicating a condition of metabolic stress and a more rapid nutrient exchange rate between soil microbial biomass and the environment in the soils under *P. halepensis* than in the soils under *C. atlantica* (Pinzari et al. 2001). Finally, it was found that the plantation also influenced the humification process as the amount of humified organic fraction stored in both organic and A horizons was highest under Pinus, and elemental and some spectroscopic characteristics of humic acids separated along the soil profile were different under the two tree stands (Dell'Abate et al. 2002a), suggesting that microflora and plant coverage play different roles in soil profile evolution, which could affect the pedogenetic processes.

7.2.4 Influence of Diagnostic and Functional Soil Features on Microbial Biomass Inside SOM Balance

The geographical investigations carried out in north Italy (Po Plain and high-terraced surfaces in Lombardy) and in central Italy on volcanic, terrigenous sandstone–siltstone and marly calcareous hills and terraced sandy coastal dune soilscapes in Lazio identified the Cmic/SOC indicator trend for about 400 pedons belonging to 24 types of soils classified at WRB second level (IUSS, 2007). The Cmic/SOC ratio, expressed as a percentage, shows the relationship between "active" and "passive" organic carbon fractions within the SOC fraction and is "considered by some to be an indicator of health or stress of the soil microbial community, a healthy, low-stress community being able to sustain a relatively high level of Cmic with a given level of SOC" (Magdoff and Weil 2004).

In the first boxplot (Fig. 7.9), the first 12 soil types are grouped according to medium–low rate of pedogenetic evolution for the main reference groups (Arenosols, Cambisols, Phaeozems, Chernozems and Umbrisols), whereas in the second boxplot (Fig. 7.10), the second 12 types are grouped according a high evolution rate (Luvisols, Alisols, Andosols, Vertisols), except for soils with dominant redoximorphic features (Stagnic and Gleyic properties) both at reference group (Gleysols and Fluvisols) and second-level qualifiers that were kept aside.

Results of both the figures show that the Cmic/SOC rate is generally higher in the Arenosols, in some Cambisols type and in all the Phaeozems (Fig. 7.11c) than in the Pachic Chernozems. The presence of redoximorphic features

Fig. 7.8 Lithic Haploxerolls (Pinzari et al. 2001; photo by C. Dazzi) (Leptic Phaeozem, WRB 2007) and soilscape with *P. halepensis* of the Sicani Mountains (West-Central Sicily)

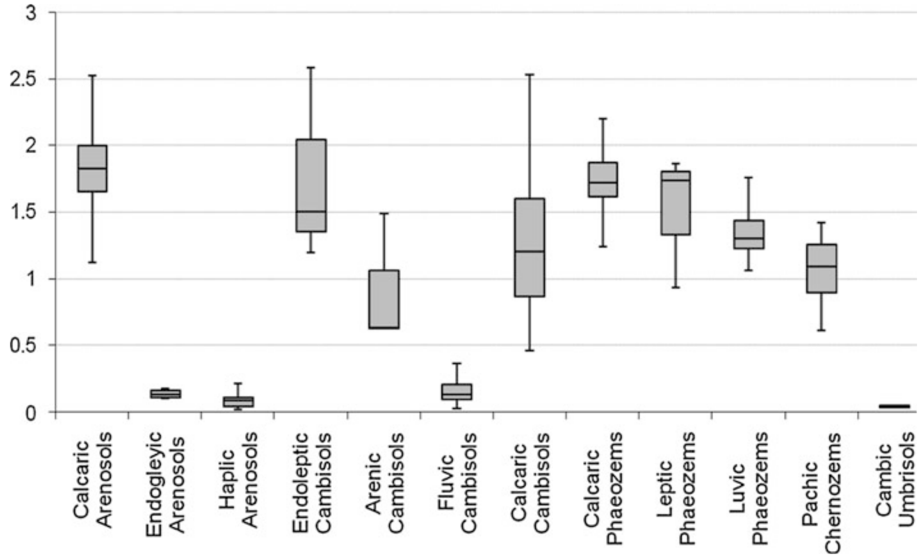

Fig. 7.9 Distribution of Cmic/SOC (%) within reference groups at medium–low rate pedogenetic evolution

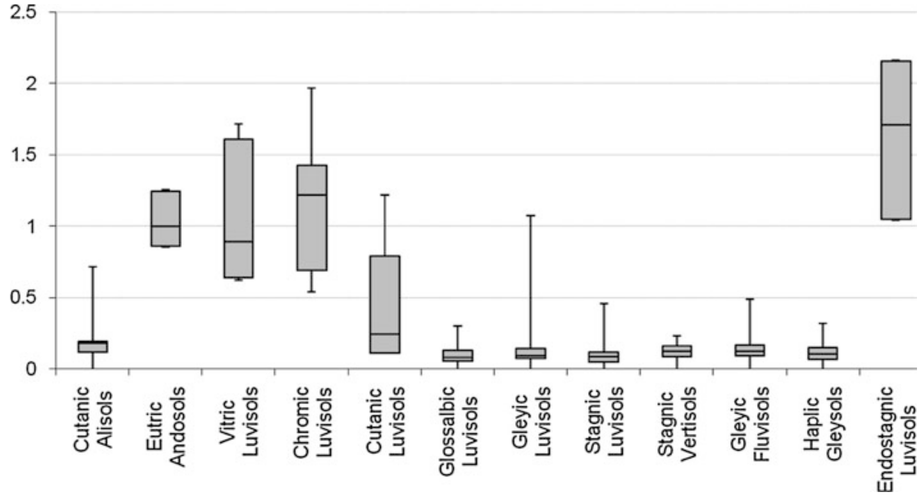

Fig. 7.10 Distribution of Cmic/SOC (%) within reference groups at high pedogenetic evolution rate

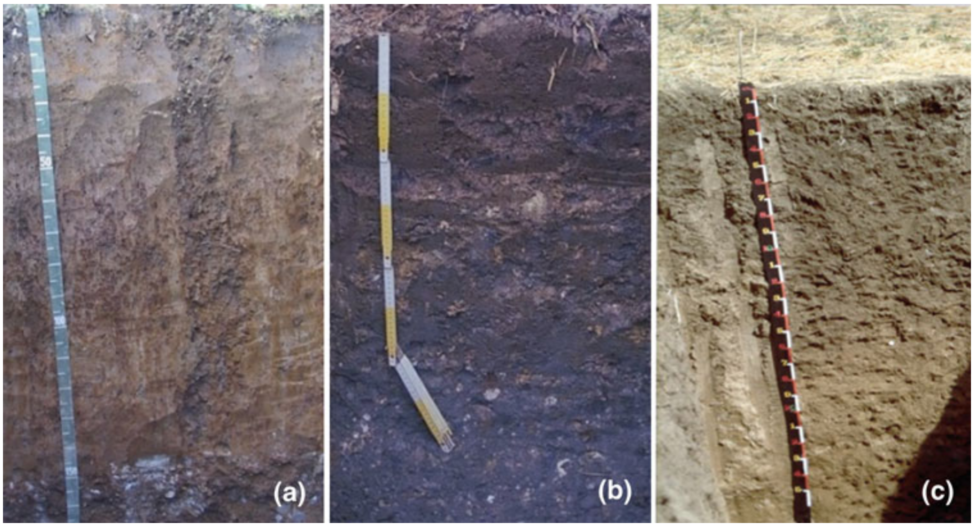

Fig. 7.11 Cutanic Alisol of the high sandy gravelly morenic terraces (**a**) and Gleysol of the low Po Plain (**b**) of Lombardy and Calcaric Phaeozem of Lazio inter mountain valley (**c**)

caused by less than perfect aerobic conditions in certain periods or all year round (as in the low-lying Po Plain areas with shallow groundwater tables) seems to strongly depress the microbial community in the presence of diagnostic Stagnic and Gleyic properties as do high aluminium values in the case of the Cutanic Alisols (Fig. 7.11a, b).

7.3 Ecological Services and Microbial Diversity (Genetic and Functional Diversity)

The ecological services provided by soil are guaranteed by microbial diversity. In this part of the chapter, we will discuss the prominence of soil biota resilience in maintaining soil fertility and sustaining ecological services, as well as providing a brief description of analytical methods.

All soil microorganisms (e.g. aerobic or anaerobic, free-living or symbiotic, culturable or non-culturable, etc.) can be used as indices for soil quality and soil health as they fulfil several key processes (e.g. nitrogen fixation, organic matter mineralization, nitrogen nitrification, etc.). A comprehensive index combining all aspects of soil complexity in a single formula and permitting accurate comparison among sites and plots has yet to be proposed. Some attempts have recently been made to transform groups of variables into indicators of soil biotic activity, using three different approaches: (a) a shopping list approach, whereby a set of different soil parameters is assessed; (b) a benchmark approach, whereby the degree of deviation between reference situations and actual measurements is evaluated; and (c) a numerical approach, whereby synthetic indices are developed (Bloem et al. 2006).

The traditional approach to studying soil microbes requires organisms to be cultivated in pure cultures and then characterized phenotypically and genotypically. However, soil microbial ecology is turning increasingly to molecular approaches, given that less than 1 % of total bacteria are generally recovered from most soils by means of conventional cultivation techniques.

In this part of the chapter, we will propose several examples of soil fertility depletion related to soil organic matter and soil biodiversity erosion.

Soil degradation forms such as soil erosion and soil contamination are among the fifteen emergencies that humankind must resolve in the third millennium to safeguard the planet and ensure its own survival (Zichichi 1993). Microbiological properties are held to be more sensitive to changes in land management and environmental conditions than chemical and physical properties, and changes in the composition of soil microflora can be crucial for the functional integrity of soil. Nannipieri et al. (2003) reviewed interrelationships between microflora, its diversity and function in soil; they discussed the impact on microbial diversity and soil functioning of different sources of stress, such as low pH and pollutants, although they did not mention genetically modified organisms (GMOs).

The ecological role of soil biodiversity in biogeochemical cycles is well known, but current scientific knowledge is unable to quantify microbial diversity loss using general criteria and shared methods tested in an environmental monitoring network. Even though microbial genetic diversity reflects the variation in species assemblages within a community, a broader view of functional diversity has advanced our understanding of the significance of biodiversity for biochemical cycling on several levels of resolution.

The first step involves using traditional approaches to determine the main chemical–physical properties of soil in order to relate soil biodiversity to soil functions and quality. The next step involves determining diversity using general approaches (i.e. microbial respiration, microbial biomass, etc.) as well as molecular approaches (Mocali and Benedetti 2010). In order to understand and monitor microbial diversity erosion processes, it is vital to proceed by analysing and comparing the information collected over a period of time. Microbial diversity of soil can only be defined by using molecular techniques monitoring data in time and space.

The lack of national monitoring data makes it extremely difficult to characterize Italian soils according to biological functions and ecological services. The only informations available are data from spot analysis of experimental fields or from research activities carried out by various authors in specific areas (Benedetti and Mocali 2008).

Microorganisms play a key role in determining soil biological functions. Measuring global biological fertility of soil provides suitable information to characterize the functionality of different soils. Benedetti et al. (2006) proposed a synthetic index of biological fertility (IBF) of soil that classified soils according to 5 different categories as shown in the following Table 7.2.

According to this ranking scheme, at a preliminary stage of classification, most Italian forest soils lie in Class V, a large part of agricultural soils managed by conventional techniques lies in Classes I and II, and all other agricultural soils are in Class III, while a minority of soils are in Class IV.

The results of two field surveys carried out at regional level are reported below.

7.3.1 IBF Monitoring Programmes and Soil Thematic Maps of Biological Fertility

Monitoring programmes of soil biological fertility were carried out both in northern and central Italy, throughout the agricultural areas of the Lombardy and Latium regions.

Table 7.2 Biological fertility index of soil (IBF)

Parameters	Range				
	1	2	3	4	5
Organic matter (%)	<1	1–1.5	1.5–2	2–3	>3
Basal respiration (ppm)	<5	5–10	10–15	15–20	>20
Cumulative respiration (ppm)	<100	100–250	250–400	400–600	>600
Microbial carbon (ppm)	<100	100–200	200–300	300–400	>400
Metabolic quotient	>0.4	0.3–0.4	0.2–0.3	0.1–0.2	<0.1
Mineralization quotient	<1	1–2	2–3	3–4	>4
For each biological parameters were prefixed 5 increasing ranges to which correspond 5 values (from 1 to 5)					
The sum of single values obtained for the six parameters (the minimum is 6 and the maximum 30) in a given soil establishes the class of biological fertility—IBF RANGE					
Biological fertility class	I	II	III	IV	V
	alarm	stress	medium	good	high
Range	6	7–12	13–18	19–24	25–30

At first level, the results were reported as relations between IBF values and soil classification types; at second level, relations with the physical and chemical characteristics of soils were analysed. Relations with soil types made it possible to create links with Soil Typological Units within the Soil System Map and to produce a first draft of the thematic map of soil biological fertility.

7.3.2 Biological Fertility Monitoring and Mapping Programmes in North Italy

In Lombardy, soil data were collected (and subsequently harmonized) from 400 sampling and monitoring points included in different monitoring programmes and projects: AgriCO2ltura, FERB I (2005–2006), FERSOIL (POC1 and POC2), Pavia and SOILQUALIMON. The projects, having different aims, used various types of soil samples, which were collected by means of different sampling strategies (single or multiple plots on the same site, different monitoring times, single or multiple times/sites). Sampling points distribution is shown on the map in Fig. 7.12.

IBF values obtained for all 400 soil sampling and monitoring sites were grouped by Soil Reference Group according to WRB (2007). The boxplot in Fig. 7.13 shows the distribution of IBF values for the 10 reference groups present in the Lombardy Po Plain and medium- and high-terraced areas with agricultural land use; very low values of IBF were found in some sites on sandy Arenosols, Luvisols and Gleysols in the low fluvial plain and Holocene terraces, placing such areas in the stress and alarm classes.

The thematic map of soil biological fertility drawn up for a 790,000 ha area in the Lombardy Po Plain—60 % of the total farmland—used the more restrictive IBF class for the Soil Map Unit (Fig. 7.14).

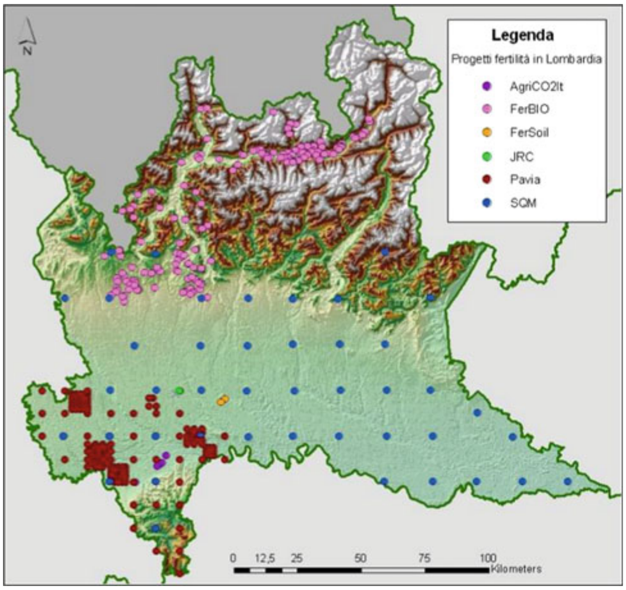

Fig. 7.12 Distribution of soil biological fertility monitoring points inside the different projects carried out in Lombardy

7.3.3 Biological Fertility Monitoring and Mapping Programmes in Central Italy

Several projects were conducted to monitor soil biodiversity in central Italy, in the Latium region, in particular. The 2004–2006 and 2010–2011 field campaigns of the BIORELA project investigated 100 and 88 sites, respectively. One hundred and twenty-seven sites producing complete data have been used so far for the purpose of IBF determination. These 127 monitoring points situated in the agricultural areas of Lazio were associated with 21 different Soil System Cartographic units.

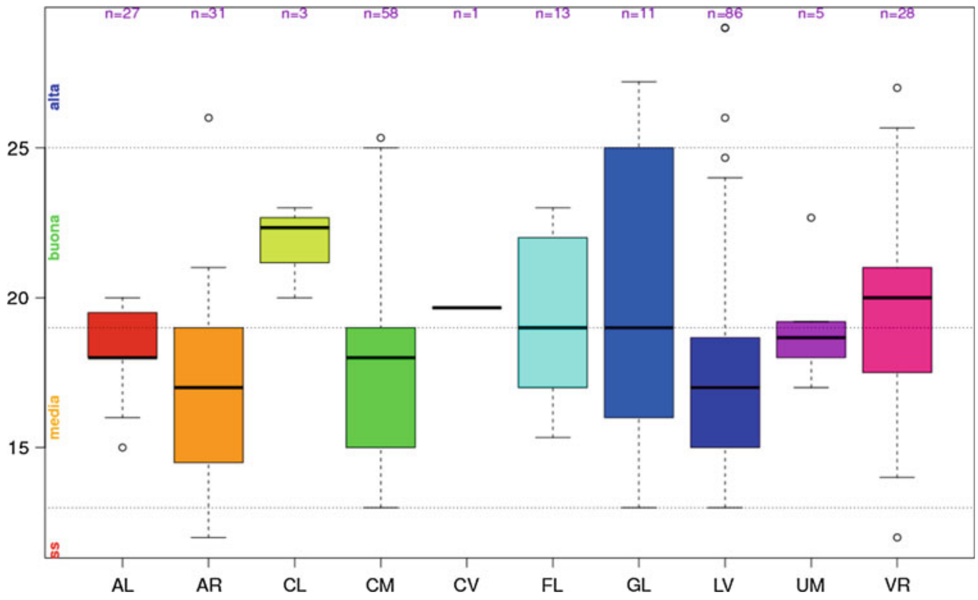

Fig. 7.13 Boxplot of distribution of IBF values within the major WRB Soil Reference Groups in monitored sites in Lombardy

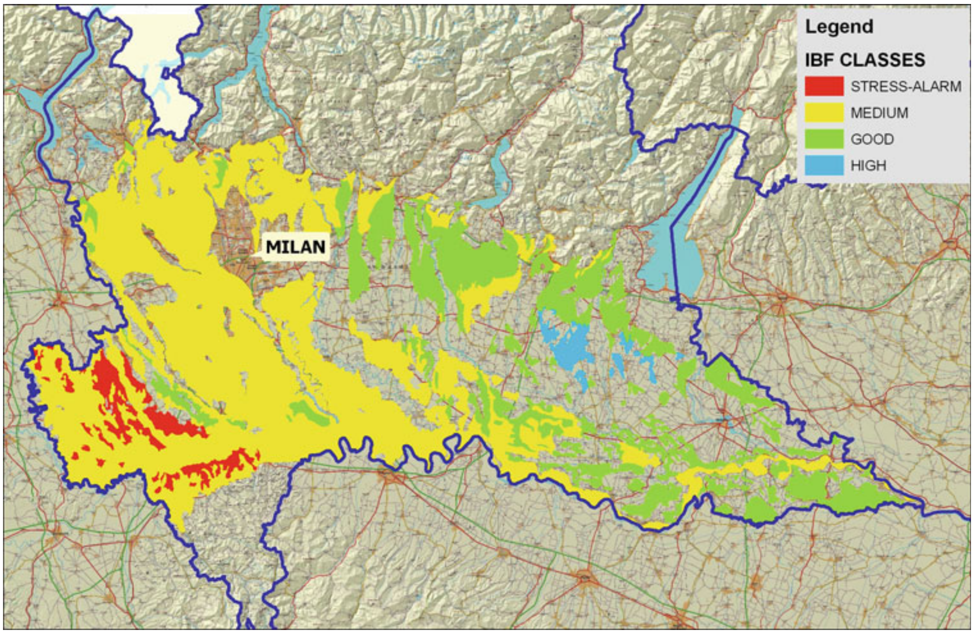

Fig. 7.14 Soil Biological Fertility Map of Po Plain and medium–high fluvio-glacial terraces in the Lombardy region

The exploration of the relationships between biodiversity and pedodiversity was based on the microbiological parameters used in the standard soil quality definition practice, intended as a biological fertility index IBF (Benedetti et al. 2006). The trend of these microbiological variables was assigned according to the placement of the monitoring points and the various soil types reported by the mapping of the various systems in the Latium region, with particular reference to the main types of soil (STS) in each mapping unit. A subsequent in-depth monitoring phase allowed us to check the correspondence of this soil information using a series of physical–chemical parameters and the characteristics of sampling biodiversity in the surface horizon concerned (class and textural fractions, total organic carbon, pH, $CaCO_3$ %).

These relationships were explored on various levels, starting with a general analysis of the IBF trend referred to soil types and classes of land use. Subsequent phases involved the in-depth study of the following: a) the distribution of performance values of individual microbiological indices grouped by general classification level (WRB referential group) and by the presence/absence of

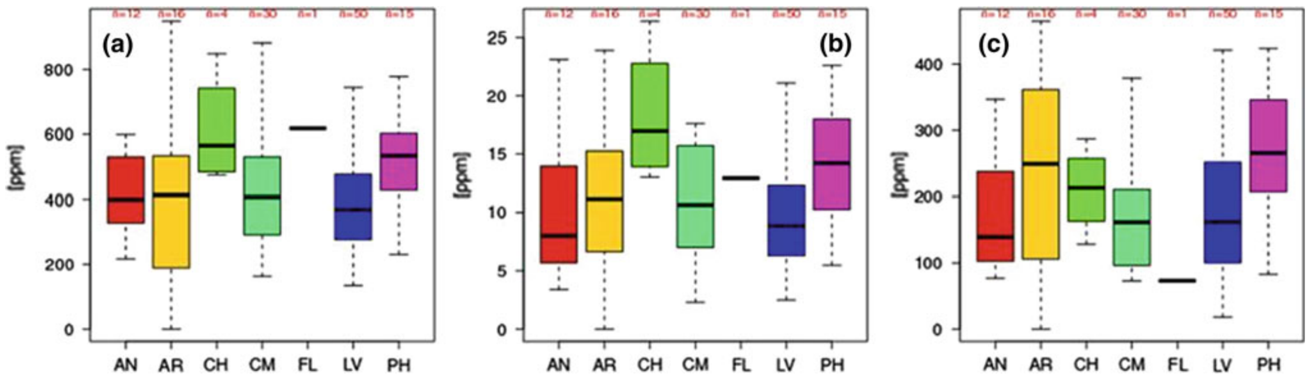

Fig. 7.15 Distribution of cumulative (**a**) and basal (**b**) microbial respiration and biomass carbon values (**c**) for different WRB Reference Group soils

horizons, properties and diagnostic materials and processes related to properties and pedogenic thresholds related to specific analytical and/or pattern recognition; b) individual "functional" soil characteristics (whether chemical, biochemical or physical) such as textural class (USDA), bulk density and packing density (an indicator of particle clustering which takes into account percentages of clay and $CaCO_3$, pH, and organic carbon content).

The first qualitative analysis shows that, overall, the distribution of IBF values ranges from fair to good for all types of soils, with high values for Luvisols (Chromic and Cutanic) and Phaeozems (Calcaric and Leptic Luvic) only and negative stress and alarm values in specific sites with Arenosols (Hypoluvic and Calcaric) and in just a few sites with Cutanic Luvisols.

On a more detailed classification level, comparison of the main microbiological indices of basal (Fig. 7.15a) and cumulative (Fig. 7.15b) respiration, and biomass carbon (Fig. 7.15c), with WRB Reference Groups indicates a high overall distribution of values for the Chernozem and Phaeozem groups and lower values for Luvisols, Cambisols and Andosols. The wide distribution of all three indices and the minimum values very low (stress and alarm classes) revealed for Arenosols seems to be related to the low soil evolution rate (Fig. 7.15).

The comparison with single physical and chemical functional characteristics (Fig. 7.16) showed positive trends in the case of transition to higher classes of apparent density and negative packing density increases; in the case of textural classes, a generally downward trend for the transition from fine to coarse classes; and finally, a tendency towards an increase in pH (from acidic to basic conditions) as well as increase in index values of $CaCO_3$ content up to a threshold value corresponding to the percentages for the presence of a diagnostic Calcic horizon, after which a marked decrease was measured.

A first rough Soil Biological fertility map was drawn up for the Latium region on the basis of the results from the 127 monitoring sites and classification within IBF classes. As in the case of northern Italy, the mapping criterion adopted used more restrictive IBF class for the Soil Map Unit (Fig. 7.17). Distribution according to the various local districts is reported in Table 7.3.

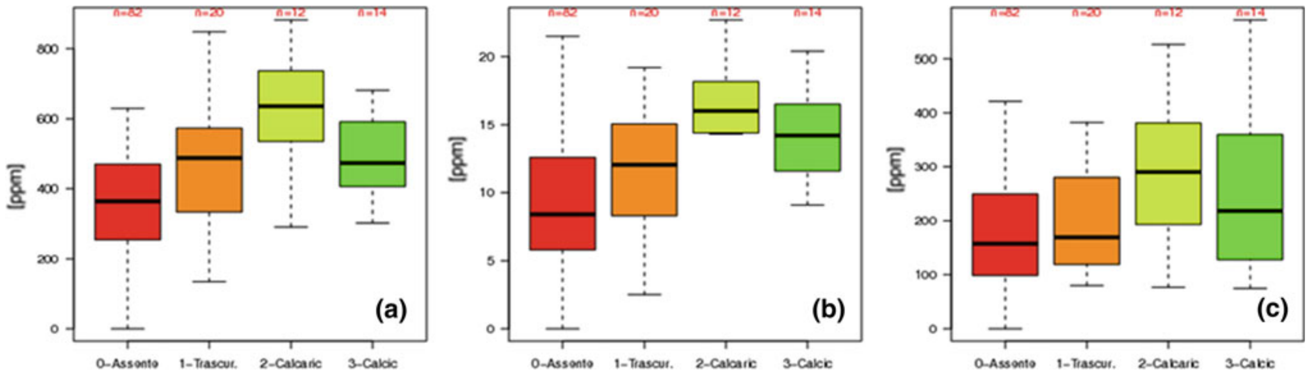

Fig. 7.16 Boxplot of the cumulative (**a**), basal (**b**) respiration and biomass carbon (**c**) distribution values versus diagnostic WRB $CaCO_3$ classes. *Box Legend* no $CaCO_3$ (red), negligible (orange), Calcaric (5–15 % of $CaCO_3$—yellow), Calcic (more of 15 % of $CaCO_3$—green)

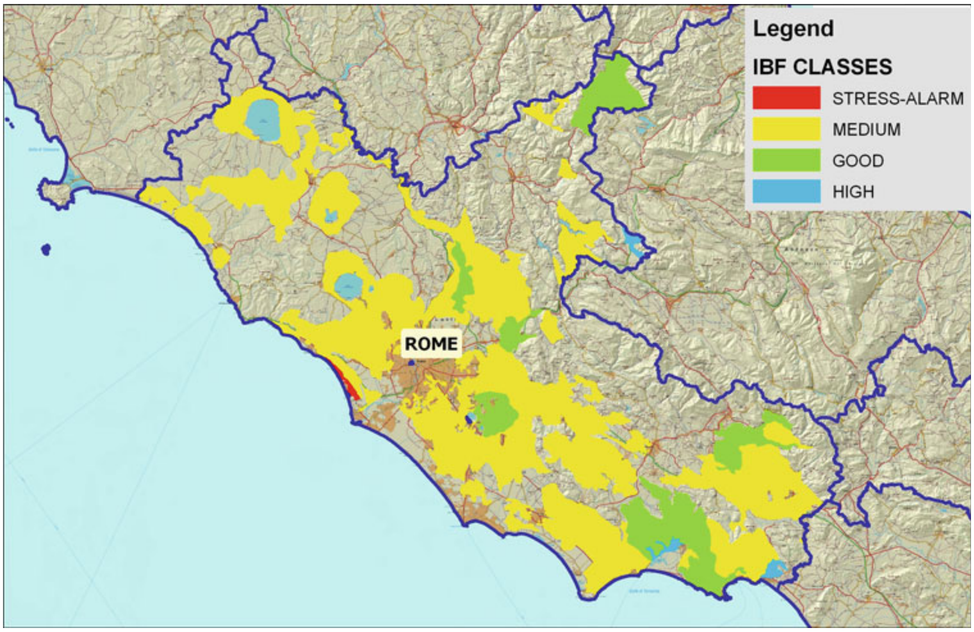

Fig. 7.17 Soil biological fertility map of the latium region

Table 7.3 Distribution of IBF values obtained in the monitoring programme carried out in various districts of the Lazio region (Rome, Latina, Frosinone, Rieti and Viterbo)

Location	Class				
	I	II	III	IV	V
Rome	0	0	30	57	13
Latina	0	0	61	22	17
Frosinone	0	0	35	59	6
Rieti	0	0	21	42	37
Viterbo	0	13	48	39	0
% on total	0	2.6	39	43.8	14.6

7.4 Soil Biological Degradation and Functional Loss

The biological erosion of the microbial genetic resources of soils is an important issue that must be taken into account when examining Italian soilscapes. Depletion in biological soil functions directly or indirectly caused by anthropic activities was identified at various soil depths. The main causes of loss of biological fertility and impairment of soil biological function are long-term use of inappropriate agricultural practices such as monoculture with high nutrient-demanding crops, common pathogen control practices such as fumigation as well as industrial pollution in the areas around cities and large urban settlements; the negative impact on soil microbial communities is even greater in areas where such soil management practices overlap. At the time of writing, we are not sure exactly to what extent natural pressures such as climate change or natural disasters worsen these effects, for example, the desertification processes taking place in vast areas in southern Italy may play an important role in these degradation processes.

Some examples of soil biological fertility status in relation to the harmful soil management practices described above are reported below. Moreover, the results of a study conducted by using biotechnological techniques revealed that different genetically modified (GM) crops could induce a significant impact on biogeochemical cycles and composition of the soil microbial community diversity, at different rates and in a wide range of soils.

7.4.1 Effects of Soil Fumigants on Monocultural Crops

This study (Mocali et al. 2008) evaluated the effect of the 1,3-D (dichloropropane) fumigant on microbial activity, microbial biomass and diversity of culturable heterotrophic

Fig. 7.18 Calcaric Arenosol and location of soilscape

microbial soil communities although they represent only a small proportion of bacteria-inhabiting soil.

The soil type was identified as a Calcaric Arenosol (WRB 2007) belonging to the Soil System with "coastal plain with dune bar and terraced dunes with artificial drainage on Aeolian deposits covered by row crops" (Fig. 7.18, lies within EU Soil Region 60.7).

1,3-D was used to fumigate soil in the Maccarese area (Rome) against nematodes. The analysis of the soil characteristics in this area, which has been cultivated with carrots for over 20 years, showed serious soil fertility depletion (sand 92 %, pH 8.3, organic matter 0.43 %; Fig. 7.19).

Fig. 7.19 Topsoil with monoculture (Carrots) from Maccarese, Rome (photo by A.Benedetti)

This case proved that fumigation with 1,3-D led to a great loss in soil biological fertility and reduction in a selected bacteria community. The amplified DNA restriction analysis produced an ARDRA profile (haplotypes), revealing the presence of only a few colonies in the soil: only 5 haplotypes corresponded to 64 % of the total bacterial species reported in Table 7.4. Selective pressure induced by 1,3-D strongly favoured microorganisms resistant to the fumigant through the formation of spores. However, it could be possible that the presence of very high percentage of Gram-positive bacteria in a fumigated soil and, in particular, of the genus Bacillus might be related to the ability of these bacteria to form spores to protect themselves from the fumigants rather than to a set of genes involved in biodegradation of 1,3-D.

7.4.2 Effects of Monoculture, Organic, Rotation Practices and Soil Natural Chemical Limitations

The biological fertility of three soils with different types of soil management was investigated using a "traditional approach": (1) Endoleptic Vitric Andosol with vegetable (Rome); (2) Eutric Cambisol with tobacco monoculture (Città di Castello, Tiberina Valley); and (3) Cutanic Luvisol with durum wheat (Paliano, Frosinone).

The three different experimental fields were characterized by different levels of physical–chemical fertility. On the basis of these characteristics (Table 7.5), the sites were identified as being representative of high (Endoleptic Vitric Andosol), medium (Eutric Cambisol) and low (Cutanic Luvisol) levels of fertility.

Table 7.4 Most of culturable bacterial species (about 64 % of the total) present in the fumigated soil

Haplotype	Species	% on total
C2L8	Bacillus firmus	26
FL13	Bacillus firmus	12.7
C2M7	Bacillus simplex	11.7
FL3	Bacillus licheniformis	8.4
F + CM7	Arthrobacter sp.	5.8

Table 7.5 General physical and chemical characteristics of the topsoils

Soil	Clay (%)	Field Capacity (%)	pH H_2O (1:2.5)	pH KC1	$CaCO_3$ (g kg^{-1})	$CaCO_3$ act. (g kg^{-1})	P_2O_5 (mg kg^{-1})	Extract. P (mg kg^{-1})	SOC (%)	Total N (%)	C/N	CEC (cmol kg^{-1})
Endoleptic Vitric Andosol	9.3	34.5	7.5	7	61	25	222	3453	2.44	0.175	13.94	27.8
Eutric Cambisol	26.5	18.0	7.9	7.2	73	23	24	145	1.18	0.131	9.01	17.4
Cutanic Luvisol	30.9	40.3	5.8	4	–	–	83	208	0.27	0.038	7.10	16.1

Table 7.6 Soil biological fertility parameters

Location	Respiration (C–CO_2 -mg Kg$^{-1)}$	Nitrification (%)	Ammonification (%)
Roma	349	100	89
Città di Castello	110	76	51
Paliano	87	55	29

The biological fertility analysis (Table 7.6) showed high values for the Andosol but extremely low values for both Cambisol and Luvisol. The soil respiration, nitrification and ammonification activity values for the latter two soils were very similar and at odds with their physical–chemical characteristics. The reasons seemed to be related to the management of the different experimental fields. In fact, the Andosol was managed according to good agricultural practices (organic fertilization, minimum tillage, plant rotation, etc.), whereas the Cambisol had serious limiting factors with regard to pH and organic matter content. The Luvisol site was a typical intensive farming site cultivated for over 20 years with a high-yield tobacco monoculture (massive mineral fertilization, deep tillage, irrigation, pesticide application and so on) (Benedetti 1983).

7.4.3 Restriction Effects on Microbial Activity by Industrial Oil Pollution

Although bioremediation of polluted soils can be achieved by using oil-degrading bacterial consortia as well as endogenous soil microorganisms, one of the factors limiting effective and complete degradation of hydrocarbons is their reduced bioavailability to soil microorganisms mainly caused by their limited solubility in aqueous media. The case study was performed on sandy soils (Table 7.7) classified as Arenic Calcic Phaeozems on low hillslopes with sandy quaternary deposits and calcareous gravel levels, located just north-west of Rome (Mezzaluna Soils of the Rome Municipality Soil Map at 1:50,000 scale, Arnoldus-Huyzendveld 2003).

This study compared the effects of adding cyclodextrin (Cy) and compost (C) upon the bioremediation of oil-polluted soil in an experimental trial (Fig. 7.20). Soils were added with three different amounts of oil (0.1, 2 and 6 % w/w) and incubated for 190 days.

Microbial biomass (Cmic) and soil respiration (Ccum) were determined in order to monitor the remediation process in microcosms. The functional and genetic diversity of soil microbial communities was determined by community level physiological profile (CLPP) and denaturing gradient gel electrophoresis (DGGE) analysis, respectively.

At the end of incubation, microbial carbon values in the bioremediated soils were higher than in the control trials. This result was caused by the enhanced mineralization

Table 7.7 Horizons and physico-chemical characterization of Arenic Calcic Phaeozem

Main analytical data/Horizons	Ap (0–30 cm)	Bw (30–50 cm)	BC (50–75 cm+)
pH (1:2.5)	7.9	8.0	8.2
Clay (%)	12	17	16
Silt (%)	6	2	3
Sand (%)	82	81	81
SOM (%)	2.4	0.7	0.6
C.E.C. (cmol kg $^{-1}$)	13.8	10.3	11.0
Base saturation (%)	100	100	100
CaCO3 (%)	4.2	6.1	8.4

Fig. 7.20 Experimental trial on Arenic Calcic Phaeozem and soil profile

processes in polluted soils (Fig. 7.21). In particular, the efficiency of carbon mineralization was higher in soils spiked with 2 % of petroleum and very low in the more polluted soils (6 % oil), suggesting a strong inhibition of microbial functions. Carbon flux behaviour differed between the more polluted soils and the others. The C + Cy combination appeared to be the most effective bioremediation treatment for 0.1 and 2.0 %, while the contribution of compost mineralization appears to be consistent.

The DGGE approach allowed us to monitor the composition of the bacterial community and its genetic diversity (Fig. 7.22). It showed differences between the communities in response to the different treatments, characterizing three microbial clusters corresponding to samples with three different levels of oil concentration, cyclodextrin and compost amounts. Samples with 0.1 % oil seem to resemble the control more than the 2 and 6 % samples although sample 0.1 PC is clustered with samples containing 2 % petroleum.

7.4.4 Impact of Cultivation of GM Crops on the Functioning of Microbial Communities

EU directive 18/2001 lays down general criteria on the release of genetically modified (GM) plants in Europe. For the first time ever, a law sets a limit for soil nitrogen and carbon recycling. Carbon and nitrogen mineralization or humification parameters should be able to detect carbon and nitrogen recycling in soil as they are indicators of biomass activity and ecosystem functions.

During the last decade, various authors tested different parameters in soil growing GM and non-GM plants (Bruinsma et al. 2003). In the present paragraph we refer about soil respiration rate, C biomass, nitrification test, humification parameters, total organic carbon and the metabolic quotient in order to evaluate the impact of GM crops. Molecular (DGGE and PCR analysis) and ecophysiological tests (Biolog analysis) were also carried out. A series of

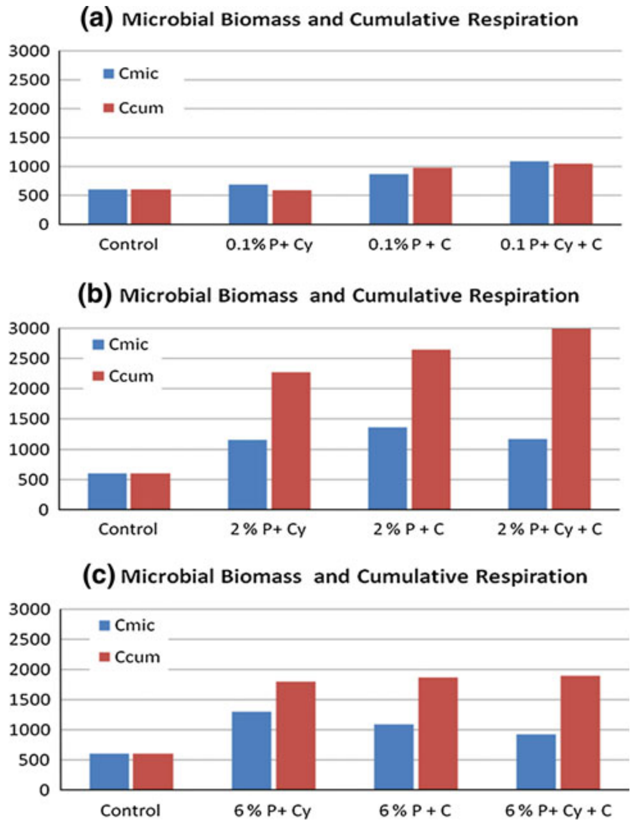

Fig. 7.21 Graph showing microbic biomass and cumulative respiration for 0.1 % (**a**), 2 % (**b**) and 6 % (**c**) oil amounts

experimental plots were evaluated for sweet rape, tomato, courgette and melon crops in central Italy (Lazio) on different types of Cambisols (Calcaric, Fluvic and Gleyic) and Luvisols (Vitric and Chromic).

Evaluation of results must take careful account of baseline biological soil fertility and microbial population management together with soil type and functional characteristics (Table 7.8). A general trend of loss in microbial biomass and a corresponding decrease in the Cmic/Corg rate was recorded for all soil types and all crops, depending on the start values. The lower the microbial biomass at start level, the greater the percentage decrease, with peaks of 40 % of the total (in the case of Vitric Luvisol with courgettes). This widespread decrease is accompanied by the enhancement of metabolic activity (qCO_2 values) that can reach values corresponding to fairly serious stress conditions (>0.3). Although the overall negative impact shown in soil biological erosion could be traced to the GM crops, further studies using molecular analysis will prove more effective in investigating plant–soil interaction within the rhizosphere in greater depth.

7.5 Soil Organic Matter, Biodiversity and Soil Physical Degradation

Following we describe some examples on how different management conditions can impact on soil organic matter content and biodiversity through soil physical degradation processes, as soil sealing, surface erosion, compaction and/or structural stability loss.

7.5.1 Structural Stability and Compaction Effects

SOM stabilization across soil types and disturbance regimes is also influenced by the rate of soil macroaggregate turnover and its changes. Microbial activity contributes to aggregate formation, stabilization and, eventually, degradation under the influence of various key factors including ratio of fungi to bacteria, soil texture and soil mineralogy. A review (Six et al. 2004) reported that in coarse-textured soils, aggregation is weakly related to microbial biomass and its metabolism products and more closely linked to the hyphal network, which is able to cross-link sand particles to form stable aggregates, whereas in clayey soils, both fungi and bacteria contribute to aggregation. Soil mineralogy was also found to influence the relationship between soil aggregation and soil biomass, with an high correlation in a Mollisol dominated by 2:1 clay minerals (illite) and no

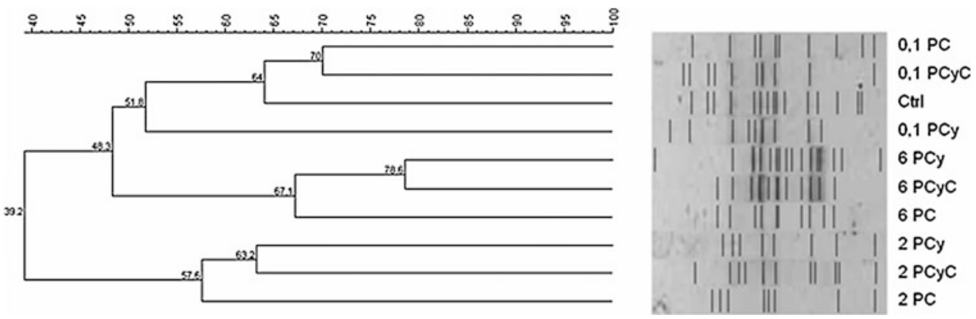

Fig. 7.22 Cluster analyses and 16S rRNA gene DGGE profiles (V6–V8 region) of eubacterial communities of polluted soils treated with cyclodextrin (*PCy*), compost (*C*), or both (*CyC*). Scale bar numbers indicate similarities among profiles

Table 7.8 Impact assessment of GM plants on soil biodiversity

Soil/Crop	Texture	pH	Corg (%)	HI	Cmic	Cmic/Corg	C–CO_2 bas.	qCO_2
Calcaric Cambisol								
Corn test	SiCL	8	1.8	0.4	343	1.9	12	0.15
Corn GM			1.8	0.4	319	1.8	12	0.16
Fluvic Cambisol								
Swiss rape test	CL	6.7	2.0	0.8	208	1.1	6	0.12
Swiss Rape GM			2.0	0.8	126	0.6	6	0.20
Chromic Luvisol								
Swiss rape test	CL	6.7	1.4	0.5	103	0.8	5	0.20
Swiss rape GM			1.2	0.6	72	0.6	5	0.29
Vitric Luvisol								
Tomato test	CL	6.1	0.6	0.4	165	2.5	2	0.05
Tomato GM			0.7	0.3	144	2.3	2	0.06
Vitric Luvisol								
Marrow test	LS	6.3	0.5	0.1	34	0.7	2	0.25
Marrow GM			0.5	0.2	20	0.4	2	0.42
Gleyic Cambisol								
Melon test	CL	6.7	5.5	0.3	159	2.9	16	0.42
Melon GM			5.6	0.3	148	0.3	14	0.39

Si Silty, *CL* Clay-loamy, *LS* Loam-silty

correlation in an Oxisol dominated by kaolinite (1:1 clay mineral) and oxides (Denef and Six 2005). On the other hand, a lesser-known aspect is related to the extent to which the physico-chemical characteristics of microaggregates and their response to environmental factors drive the microbial community structure and activity by determining the ecological niches of various microbial populations.

The Italian soils examined produced similar results in terms of distribution and stability of microaggregates, which varied according to soil type and SOM level. An experimental activity was carried out to verify the effectiveness of various Good Agricultural and Environmental Conditions (GAEC) standards laid down in the new EU CAP statements upon 6 different plots located in different Italian environments (Fig. 7.23): (1) Cutanic Luvisol on low Po Plain sandy terraces; (2) Vertic Cambisol on pliocene marine sediments on hilly slopes in central Italy; (3) Calcaric Cambisol on hilly fluvio-lacustrine sediments in central Italy; (4) Vitric Luvisol on volcanic plateau near Rome; (5) Eutric Vertisol on Campidano alluvio-lacustrine reclaimed areas in south Sardinia; (6) Grumic Calcic Vertisol on fluvio-lacustrine quaternary sediments on terraced areas in north Apulia (Dell'Abate et al. 2011).

Changes in microaggregate type and density were studied under controlled soil moisture and tillage conditions (Table 7.9). The results showed that although SOM content was almost identical, the distribution of microaggregates measured as mean weight diameter varied considerably within the 8.0–0.25 mm range as did the average bulk density of the same. In particular, Vertisols with dynamic clay minerals (mainly smectite and vermiculite) had low microaggregate density and distribution mainly in the smaller size classes, while central Italian Cambisols with different clay minerals (mainly illite) revealed fairly high density and distribution in the larger size classes (Fig. 7.24).

Fig. 7.23 Location of the 6 CRA experimental plots

7.5.2 Soil Compaction, Crusting and Erosion Effects

Soil management is crucial for the prevention and control of its degradation. Different tillage systems such as deep ploughing, shallow ploughing, minimum tillage and ripper subsoiling all have different effects on soil conditions. The adoption of ripper subsoiling tillage is capable of reducing the structural damage caused by deep ploughing and of lessening the risk of formation of surface crusts and presence of compacted layers in the profile according to the findings of the micromorphological analysis and quantification of the pore system (Pagliai et al. 2006). Moreover, soil managed using ripper subsoiling conserves more organic carbon—especially in the top layer—and has greater amounts of organic matter than soils undergoing deep ploughing. Two sites located in Tuscany hillslopes on fluvio-lacustrine silty-clay deposits (site 1) and on marine silty-clay deposits (site 2), typical of hilly central Italian soilscapes, were investigated inside the Project "ATLAS—Indicators of Soil Quality" (Dell'Abate et al. 2006a).

The soils of these environments are quite similar: a Calcaric Vertic Cambisol (site 1) and a Vertic Cambisol (Fig. 7.25; site 2); even though the former is typical of udic and ustic soil moisture regimes and the latter of xeric ones, they both contain small amounts of organic carbon and are characterized by low structural stability and a poor regeneration capacity. This type of soils must be managed correctly to minimize the potential risk of formation of surface crusts, sealed surfaces and the risk of compaction by farming machinery. The resulting hazardous degradation in a hilly environment, reduced rainwater infiltration rate and creation of preferential surface runoff courses all play a role in triggering widespread rill and gully erosion processes.

Soil microbial activity was verified by determining soil microbial biomass carbon and respiration and then using the metabolic quotient (qCO_2) and C biomass/total organic C (Bc/TOC) ratio. Data concerning the quantity and activity of the microbial biomass for these two different situations demonstrated that ripper subsoiling (RS) is a better management practice than deep ploughing for the maintenance of total organic carbon and of the living fraction. In fact, microbial biomass content is greater than in RS management for both depths (Table 7.10). Results obtained for the two different management practices (Dell'Abate et al. 2006a) showed that qCO_2 was comparable with the two layers in the soil undergoing ripper subsoiling (RS), while it was higher at a depth of 20–40 cm in the soil where deep ploughing (DP) was adopted. A high value of qCO_2 in the ploughed zone (DP) reveals a lack of equilibrium due to the practice adopted. This conclusion was also confirmed by the Bc/TOC ratio: the value of microbial biomass in the deepest layer of the DP case was half the value found in RS to the same depth, while total organic carbon was practically constant.

The impact of two other types of soil management, a comparison of continuous wheat and continuous alfalfa, was assessed for site 2 in a field experiment established since 1994. The soil porosity values obtained in the 0–5 cm soil depth for the two areas on which the crops were grown showed that after heavy rain, soils supporting alfalfa had a higher porosity percentage than those from the wheat-growing area. The protective action of the alfalfa vegetation cover decreased soil surface vulnerability to the impact of rainfall and thus lessened the risk of formation of crusts. Moreover, wheat did not seem to be the most suitable crop as it depleted organic matter in the top soil horizon, while alfalfa conserved the organic matter better. Removal of the finest soil particles by water erosion led to preferential loss of the most stable and most strongly absorbed organic fraction (humin) that accumulated in the deeper layer (Pagliai et al. 2006).

The quantity of microbial biomass in the soil cultivated with alfalfa (L) was higher than in the soil cultivated with wheat (W). This was also confirmed by respiration data, which showed that the alfalfa crop seems more effective than wheat in preserving total soil organic carbon (Table 7.11). The C biomass/total organic carbon ratio had comparable values for the two crops at every depth as well as specific respiration (qCO_2). The latter was higher under both the crops in the deepest layer, indicating a metabolic stress condition. In brief, the alfalfa covering had a beneficial effect on the quantity of organic carbon and microbial biomass, whereas microbial metabolism was not affected by

Table 7.9 Texture, SOM and microaggregate bulk density under "*tilth*" conditions for 6 soils of CRA experimental plots

Soil type	Sand (%)	Clay (%)	Silt (%)	SOM (%)	Microaggregate bulk density
Cutanic Luvisol	44.88	20.88	34.24	1.43	1.71
Vertic Cambisol	11.00	42.00	47.00	1.48	4.82
Vitric Luvisol	31.05	21.85	47.10	2.03	1.18
Eutric Vertisol	41.84	33.58	24.58	2.07	0.94
Calcaric Vertic Cambisol	8.60	37.90	53.50	2.23	4.28
Grumic Calcic Vertisol	21.00	42.00	37.00	2.44	0.50

the different crops (Dell'Abate et al. 2006a). The rationale for erosion environmental risk is to avoid sowing wheat in these soils, but indubitably, wheat is a more profitable crop than alfalfa.

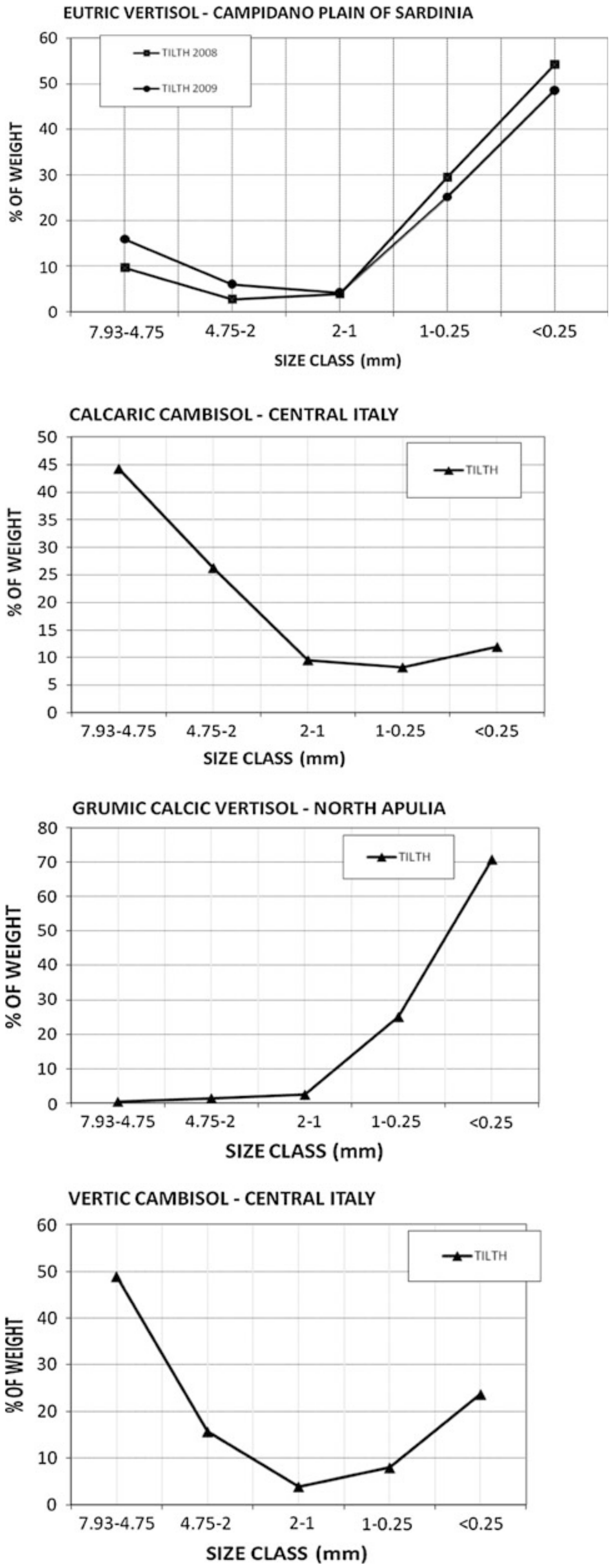

Fig. 7.24 Graphic distribution of microaggregates inside size classes as weight percentage for different soil types

7.6 Conclusions

This chapter discussed soil functions and ecological services mainly by considering soil microbial resources, a powerful driving force for many processes in soil, starting with soil formation. Many soil functions were not described given that they did not aim to provide a comprehensive overview of all ecological services linked to soil functions. This decision was mainly dictated by the fact that despite the growing impact of microbiological studies upon soil research, we have yet to attain an in-depth knowledge on how to manage soil microbial resources at field scale in order to preserve and improve soil functions. A number of examples relative to Italian soils were reported to demonstrate the possibility of describing soil functions and microbial activity at local level. We also drew up soil biological fertility maps for the Latium and Lombardy regions. The results of activities carried out in the different sites revealed the need to arrange the indicators on a hierarchical scale according to the study goal. The topic of hierarchical scales of different indicators is widely debated, and researchers are obviously more familiar, and expert, in using the standard parameters adopted in their laboratories.

In the case of Sect. 7.4 describing fumigated soils, the use of molecular techniques on culturable bacteria allowed us to verify the extent of genetic erosion induced by the fumigant. In addition, the bacteria isolated could be used to enhance the bioremediation of further fumigated soils. In the case of intensive monoculture adopted in Città di Castello, a significant reduction in biological fertility occurred although it is impossible to relate the results to any change in soil microbial diversity. Cases of genetic erosion of microbial genetic resources by intensive and aggressive agricultural management were also described. In these sites, IBF revealed loss in biological fertility. In the last example, the remediation of contaminated soils led to the modification in eubacterial diversity, revealed by DGGE. In this case, it was possible to evaluate the shift in the dominant bacterial species but not to identify them. Thus, different approaches are required in order to assess the erosion of microbial diversity, and an ecosystemic approach is recommended. In fact, the combination of appropriate traditional and molecular techniques allows us to monitor microbial diversity as well as provide a contextual environmental consequence.

Fig. 7.25 Vertic Cambisol on marine silty-clay sediments in hilly soilscape (Volterra, Tuscany)

Table 7.10 Soil microbial biomass carbon (Bc), C biomass/total organic carbon ratio (Bc/TOC) and metabolic quotient (qCO_2) in site 1

Sample soil (cm)	Bc (mg/kg)	Bc/TOC (%)	qCO_2 (μgCO_2-C/mg Cmic.h)
(RS) 0–20	203.8 ± 26.9	2.290 ± 0.004	0.0013 ± 0.0003
(RS) 20–40	137.7 ± 23.6	1.996 ± 0.004	0.0017 ± 0.0003
(DP) 0–20	121.3 ± 69.8	1.989 ± 0.012	0.0019 ± 0.0011
(DP) 20–40	73.8 ± 9.8	1.118 ± 0.010	0.0034 ± 0.0008

Table 7.11 Soil microbial biomass carbon (Bc), C biomass/total organic carbon ratio (Bc/TOC) and metabolic quotient (qCO_2) in the site 2

Sample soil (cm)	Bc (mg/kg)	Bc/TOC (%)	qCO_2 (μgCO_2-C/mg Cmic.h^{-1})
W 0–20	153.0 ± 40.2	3.188 ± 0.004	0.0017 ± 0.0005
W 20–40	89.9 ± 43.6	1.427 ± 0.008	0.0032 ± 0.0016
L 0–20	263.9 ± 144.0	3.341 ± 0.018	0.0013 ± 0.0007
L 20–40	151.3 ± 63.1	1.780 ± 0.007	0.0029 ± 0.0014

Finally, we reported some examples on correlation of soil organic matter content, microbial activity and other physical–chemical soil characteristics to demonstrate the possibility of qualifying soil quality in terms of soil functions.

Italy has yet to put into place a network monitoring biological fertility of soils in relation to soil function conservation. Currently, there are only data from individual sites at regional level (Lombardy, Latium, Marche, Sardinia and Piedmont) or at the level of experimental fields as in Fagna (Florence), Vicarello (Florence), Tor Mancina (Roma), all of which were reported.

This chapter aims to propose a methodological approach to the characterization of soil microbial resources by means of microbiological parameters of greater relevance and to exploit them at national level in monitoring programmes according to hierarchical level (Bloem et al. 2006; Mocali and Benedetti 2010).

A guide to the hierarchical use of indicators was provided by OECD requirements, whereby indicators must: be clearly correlated with a certain phenomenon or a certain feature that is being investigated or monitored; be highly correlated with the above-mentioned effect with minimum statistical variability; be unobscured by much less significant responses; have a sufficiently generalized, albeit not identical, validity in many analogous situations (OECD 1999).

It is clear that hierarchical levels can change depending upon whether the indicator is required for monitoring, for accurate characterization of a particular environment, for assessing or restoring previous changes or for starting up research. If the aim is to study soil quality in terms of fertility, the following hierarchical level could be applicable: C biomass and respiration rate, functional diversity, genetic diversity and case-by-case in-depth probes (heavy metals, genetically modified organisms, air pollution, erosion, etc.).

The first step in assessing biological soil fertility, that is, the expression of microbial turnover is to perform simple biochemical tests. The same tests can be used effectively for environmental monitoring. The next step could be to study the functional diversity of the ecosystem, followed by genetic diversity and then case-by-case in-depth probes. To date, some methodologies, for example, the ecophysiological profile and bacterial and fungal DNA studies cannot be utilized in nationwide, large-scale monitoring programmes.

Moreover, a minimum hierarchical level must also be identified for other correlated indicators in order to prevent false-negative and false-positive results. In the case where soil fertility is related to crop yield, physical fertility is just as important as chemical and biological fertility. Obviously, the correct functioning of aerobic microorganisms will not occur under, for example, conditions of oxygen limitation, extremes of pH or elevated salinity, and so on. Thus, it is crucial to build other hierarchical scales, which could be represented by the following for chemical soil indicators: organic matter, pH, available nutrients, various types of pollutants, etc.

The following factors could be adopted for physical soil fertility indicators (Vignozzi and Pagliai 2006): porosity, aggregate stability, compactness, sealing along the profile, structure loss, superficial crusts and potential risk of their formation, fissuring and erodibility.

The hierarchical scales will then be put together in an attempt to identify a minimum dataset taken from the point where the different hierarchical scales overlap. The scales used in different studies will obviously differ and range from environmental, pedological and agronomic indicators or factors to social and economic factors.

The examples reported in this chapter represent good applications of this methodological approach to describe Italian soils in terms of biological function.

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